CONSTRUCTION STAGE ANALYSIS OF RCC FRAMES

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CERTIFICATE

This is to certify that the project report entitled

"Construction Stage Analysis of RCC Frames"

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is a bonafide work completed under my supervision and guidance in partial fulfilment for the award of Bachelor of Engineering in Civil Engineering of Deogiri institute of Engineering and Management Studies, Aurangabad under Dr. Babasaheb Ambedkar Marathwada University, Aurangabad.

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ABSTRACT

While analyzing a multistorey building frame, conventionally all the probable loads are applied after modeling the entire building frame. But in practice the frame is constructed in various stages. Accordingly, the stability of frame varies at every construction stage. Even during construction freshly placed concrete floor is supported by previously cast floor by formwork. Thus, the loads assumed in conventional analysis will vary in transient situation. Obviously, results obtained by the traditional analysis will be unsuitable. Therefore, the frame should be analyzed at every construction stage taking into account variation in loads. The phenomenon known as *Construction Stage Analysis* considers these uncertainties precisely. This project analyzes several numbers of multistorey reinforced concrete building frames of different bay width and length, storey height and number of stories using STAAD*pro*, followed by the construction stage analysis of each model. Also all full frame models are analyzed for earthquake forces in Zone - II (IS 1893:2002). Finally, a comparative study of Axial forces, Bending moments, Shear forces and Twisting moments was done at every storey for full frame model (without earthquake forces) and construction stage model (without earthquake forces). Also the results of full frame model (with earthquake forces) were compared to construction stage model (without earthquake forces) for knowing the significance of any one of them.

***Keywords*:** Construction Stage Analysis, Construction Sequence Analysis, Construction loads, Sequential gravity loads.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

Chapter 1. INTRODUCTION

1.1 General

A structure is most vulnerable to failure while it is under construction. Structural failures involving components, assemblies or partially completed structures often occur during the process of construction. A collapse during construction may not necessarily imply a construction error. It may be the result of an error made during design. A collapse of structural steel, stadium expansion project, 1987 in the Pacific Northwest served to remind construction professionals of the vulnerability of incomplete structures. A failure during construction is always economically undesirable, and in the extreme case may result in injury or death. Efforts to reduce the potential for structural failure during the construction phase will reduce the risk of injury, and of unforeseen costs and delays.

Possibly the most impressive structural failures during construction are those resulting from the lack of stability. The designer conceives of the structure as a completed entity, with all elements interacting to resist the loads. Stability of the completed structure depends on the presence of all structural members, including floors. During the process of construction, however, the configuration of the incomplete structure is constantly changing, and stability often relies on temporary bracing. Construction sequencing is extremely important in evaluating the stability of incomplete structures. Another recurring cause of structural failures during construction is excessive construction loading. Often the loads applied to structural members while construction is taking place, are in excess of service loads anticipated by the designer. This is due to fresh floors are supported by previously cast floors by the falsework system. Analysis of the stability requirements for these irregular, incomplete, and constantly changing assemblies presents a challenging problem to the most capable structural engineers. To ensure stability at all times, account shall be taken of probable variations in loads during construction, repair or other temporary measures. The ‘Construction Stage Analysis’ that reflects the fact of the sequential application of construction loads during level-by-level construction

of multistorey buildings can provide more reliable results and hence the method should be adopted in usual practice.

1.2 Justification

The structural analysis of multistorey buildings is one of the areas that have attracted a great deal of Engineering research efforts and designers' attention. There is one area, however, which has been ignored by many previous investigators, i.e., the effects of construction sequence in a multistorey frame analysis. In the structural analysis of multistorey buildings, there are three important facts that have very significant effects on the accuracy of the analysis but are seldom considered in the practice. They are:

1. The effect of sequential application of loads due to the sequential nature of construction;
2. The consideration of variation in loads during construction; and
3. The differential column shortening due to the different tributary areas that the exterior and interior columns support.

The effect of the sequential application of loads due to the sequential nature of construction is an important factor to be considered in the multistorey frame analysis *(Figure 1.1)*. In fact, the structural members are added in stages as the construction of the building proceeds and hence their dead load is carried by that part of the structure completed at the stage of their installation. Therefore, it is clear that the distribution of displacements and stresses in the part of the structure completed at any stage due to the dead load of members installed by that stage does not depend on sizes, properties, or the presence of members composing the rest of the structure. The correct distribution of the displacements and stresses of any member can be obtained by accumulating the results of analysis of each stage. Ignoring this effect may lead to the seriously incorrect results of analysis, particularly at the upper floors of the building. Therefore, it is necessary to calculate the load distribution and analyze the structure at every construction stage and to make sure that the loads carried by the supporting components do not exceed their strength. However, it is rather difficult to estimate accurately the load distribution in

the system because of the time dependent behaviour of building materials and the complexity of construction stages.

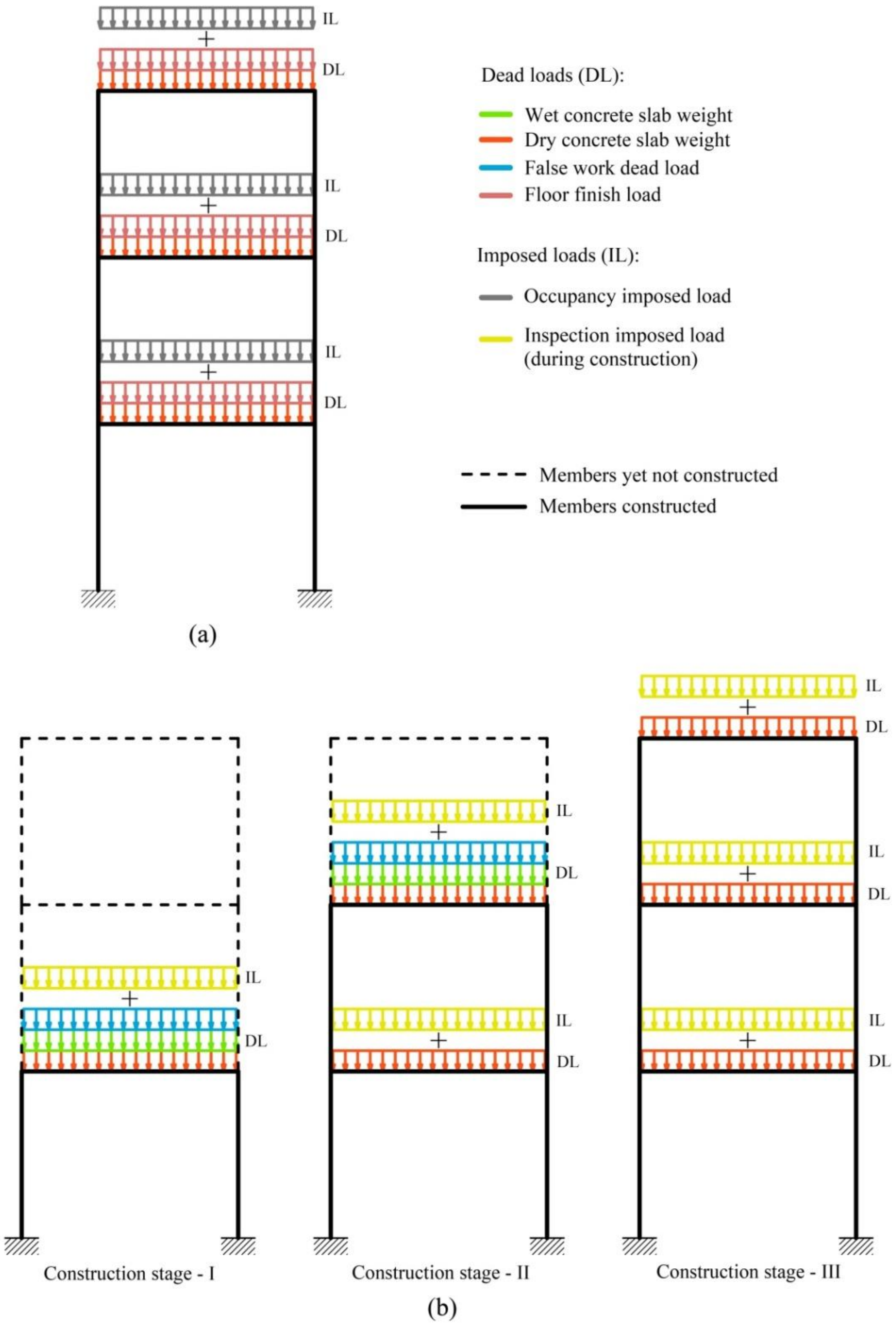

Figure 1.1 Frame Analysis: (a) Conventional Analysis; (b) Construction Stage Analysis.

The differential column shortening due to the different tributary areas that the exterior and interior columns support, also affects the distribution of stresses in the members of the structure. The exterior column in a building is loaded roughly

one-half of the gravity load to which the interior column is subject (e.g., weight of beams, columns, walls and slabs, exterior skin of building, etc.) (*Figure 1.2*). In many design practices, however, there is a tendency to design exterior columns having nearly equal cross-sectional areas to the interior ones, mainly because additional cross sections are required in the exterior columns in order to resist the forces induced by the overturning moments due to the lateral loads. Therefore, there exists a substantial inequality between the ratio of applied gravity load to the cross-sectional area of an exterior column and that of an interior one. This inequality may cause a differential shortening in the exterior and interior columns of the frame. In a multistorey buildings, considerable amounts of the differential column shortening is accumulated in the members of the upper stories, and so are the bending moments and shear forces when the gravity load analysis for the frame is performed by an ordinary method, such as the finite element analysis of complete frame as a whole.

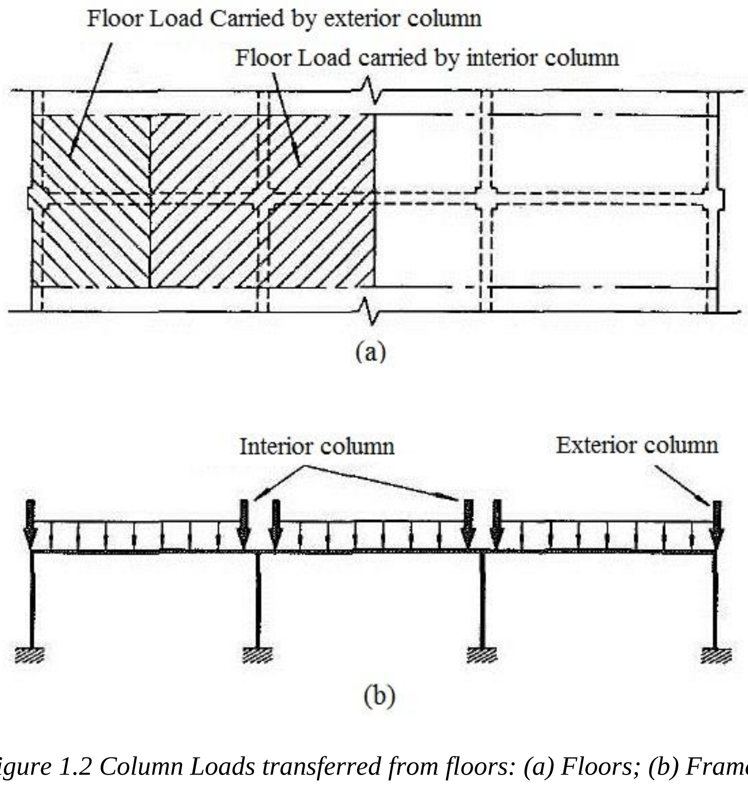

Figure 1.2 Column Loads transferred from floors: (a) Floors; (b) Frame.

These differential column shortenings and bending moments due to the dead weight may be overestimated and considered "incorrect" because the ordinary frame analysis methods do not take into account the sequential nature of the construction and of the application of its weight.

1.3 Terminologies

***Conventional Analysis*:** A linear analysis approach in which all the probable loads on the structure are applied after modeling the entire frame.

***Construction Stage Analysis*:** A non-linear analysis approach in which the loads are applied sequentially and the structure is analyzed at various stages corresponding to the construction sequence.

***Full Frame Model*:** A frame model analyzed by conventional analysis approach.

***Construction Stage Model*:** A frame model analyzed by construction stage analysis approach.

Floor: Floor is defined to include the beams of the same floor and the columns immediately beneath the floor.

1.4 Objectives of study

Bearing in mind the above discussion, main objective of this work is to reduce the potential for structural failure during the construction phase ultimately reducing the risk of injury, and of unforeseen costs and delays in construction projects. As per IS 456:2000, Clause 20.3, *'To ensure stability at all time, account shall be taken of probable variation in dead load during construction, repair or other temporary measures'.* Through this work it is intended to draw the attention of practicing Engineers towards the above mentioned clause.

For satisfying the above mentioned objectives, following points were studied:

1. To observe the behaviour of structure during construction at different stages.
2. Comparing the results of these stages with full model of the structure.
3. Observing the effect of change in:
    a. Number of storeys;
    b. Bay width/length; and
    c. Storey height.

1.5 Scope of study

This project deals with a comparative study of Axial forces, Bending moments, Shear forces and Twisting moments done at every storey for full frame

model (without earthquake forces) and construction stage model (without earthquake forces). Also the results of full frame model (with earthquake forces) were compared to construction stage model (without earthquake forces) for knowing the significance of any one of them. Earthquake forces are considered for Zone-II in accordance with IS 1893:2002 – Part-I.

The project analyzes several models of G+5 and G+7 RC building frames using STAAD*pro*, by changing the following parameters governing the stiffness of the members:

1. Storey height of 3m and 4m; and
2. Bay width ranging from 4m to 6m (i.e. 4m, 5m, and 6m).

Earthquake forces were not considered while analyzing the construction stage models. Around 69 numbers of reinforced concrete frames were modelled and analyzed.

1.6 Outline of Report

Chapter 1: The brief introduction of the topic of work is discussed. The topic *Construction Stage Analysis* is tried to explain in depth, emphasising its importance and significance in usual practice. After reviewing this chapter, the reader will be able to clearly distinguish between the conventional analysis of multistorey frames and *Construction Stage Analysis*. Also the aim and scope of this project is discussed in this chapter.

Chapter 2: An evaluative comparison of various pieces of research Is discussed in this chapter. Several international and national journal papers were analyzed and evaluated for the purpose of finding the gap of information in the topic of interest. It shows the reader what previous research has been done in the field of our concern, critiques previous methodology, and evaluates prior studies to show an information gap which this project will try to fill.

Chapter 3: After illustrating the gap of information in previous research literature, the research methodology used for performing the work is explained precisely in

this chapter. The geometry and boundary conditions and there evidences, for various models used in the study is discussed in detail. The chapter clearly explain the reader, calculations of various construction loads and their sequential application following the sequence of construction. It will make crystal clear the method of comparison of responses of forces in terms of axial forces, bending moments, twisting moments and shear forces for full frame model: (without earthquake forces), full frame model: (with earthquake forces) and construction stage model.

Chapter 4: In this chapter, actual statements of observations, including statistics, tables and graphs are presented. Comparative results of axial forces, bending moments, twisting moments and shear forces; precisely explaining the percent variation for the compared models as discussed earlier are tabulated in this chapter. For the purpose of jury, the actual values of various responses are presented graphically.

Chapter 5: Conclusions in line with the objectives discussed in chapter 1, are summarised here.

Chapter 2. LITERATURE REVIEW

2.1 General

Structural Analysis of multistorey buildings is very much known and old area of research field. Evaluation of various uncertainties are always recognized and investigated every new day. Since early 1950s (Neilsen 1952; Grundy and Kabaila 1963; Agarwal and Gardner 1974; Noble 1975; Fattal 1983; Sbarounis 1984; Lew 1985; Liu et al. 1986), the uncertainty of excess loads on slabs due to formworks and various construction logistics during construction is being investigated. It was found that during construction slabs carry loads in excess of service life loads. The problem was well researched for the loads of formwork and imposed loads during construction. Even due to the time dependent behavior of cement concrete structures the conventional analysis approach does not gives reliable results. To tackle with the above mentioned uncertainties, various approaches were made. These uncertainties generally follow the sequence of construction process of the building. Therefore, while analyzing the buildings considering the sequential application of loads and construction process, the instability of incomplete structure created another problem. This phenomenon is still boom amongst many researches since 1970s. In 1978, S.C Chakrabarti, G.C. Nayak and S.K. Agarwala studied the effect of self weight only during construction process of buildings. Choi and Kim (1985); Saffarini and Wilson (1983) also dealt with the same problem independently but they considered the effect of differential column shortening under dead loads only and unfortunately paid less attention to the responses of various forces due to excess construction loads and instability of incomplete structures.

The aforementioned uncertainties were amongst the reasons advocated by an ASCE member Kenneth L. Carper (1987) for most of the structural failures during construction. These uncertainties increased the computational efforts for the analysis of multistorey buildings. Choi and Kim (1985) used the *"One floor at a time"* analysis approach for solving the problem. But it was beyond the human computational efforts. In 1992 Chang-Koon Choi, Hye-Kyo Chung, Dong-Guen Lee, and E. L. Wilson proposed a simplified analysis approach known as "*Correction Factor Method (CFM)"* considering only dead loads. These two

methods are discussed in detail in the upcoming sections. As these methods are not sufficient to tackle all the uncertainties, much structural analysis software's are developed and improved to perform the *Construction Stage Analysis* precisely.

2.2 Basic Concepts

Consider a typical floor (r^{th} floor) of a frame in figure 4.1 (here a floor is defined to include the columns immediately beneath the floor). Assuming the building is constructed one floor (or a group of floors) at a time, the r^{th} floor is constructed on the top of the frame that was completed so far [i.e., up to $(r - 1)^{th}$ floor] and in which the column shortening due to dead weight already took place before the construction of the r^{th} floor is started. Moreover, since each floor is leveled at the time of its construction, the deformations that occurred in the frame below, before the construction of the floor, are of no consequence. Therefore, the frame below can be considered weightless in the analysis model for evaluating the behavior of the r^{th} floor.

2.3 "One Floor at a Time" Approach Analysis

Excluding the effects of the deformation due to the gravity load in the frame below, a more accurate structural analysis model can be established for each floor. For the analysis of the entire frame, a progressive (successive) nature of the analysis with "one floor at a time" approach may be employed. As construction proceeds, floors are added to the frame gradually and the r^{th} floor is subjected to its own weight plus the load from the floors above it, as shown in figure 2.1. The intensities of the loads from upper floors can be reasonably approximated by the column forces of the $(r + 1)^{th}$ floor that are obtained in the previous analysis.

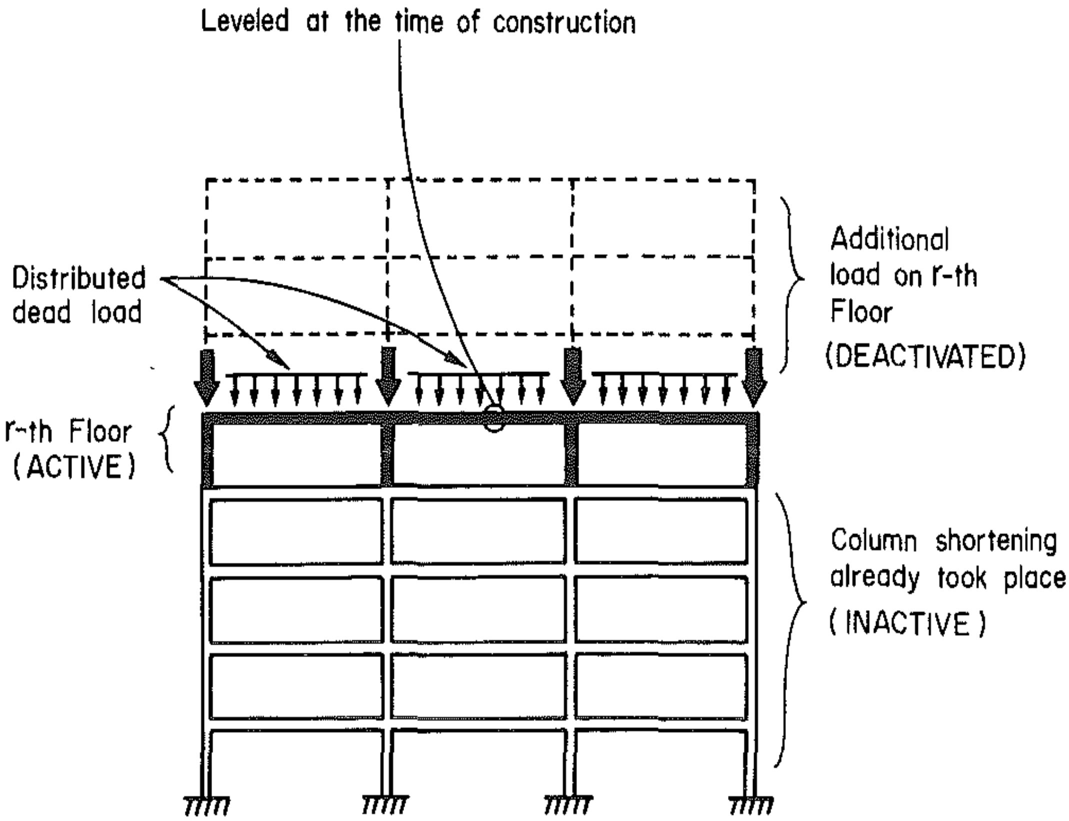

Figure 2.1 Modeling for typical floor analysis

Based on the preceding description, a structural model for the behavior of the r^{th} floor is developed with the concepts of "Active," "Inactive," and "Deactivated" floors as shown in figure 2.1. The active floor designates that the behavior of the floor is actually sought at this analysis, while the response of the inactive floors is not sought. The "deactivated" floors, i.e., the floors above the active one, are modeled only as the loads acting on the active floor. The active floor has its stiffness and is loaded by its own weight plus the forces that are equivalent to the column forces of the floor immediately above it.

On the other hand, the inactive frame has normal stiffness, but its weight is not activated in the analysis of the r^{th} floor. This corresponds to neglecting the effects of the column deformation in the inactive frame due to its weight in evaluating the behavior of the r^{th} floor. In this case, the inactive frame plays the role of elastic supports for the active floor above. Excluding the effects of the dead weight of the inactive frame in the analysis of active floor is equivalent to taking the

construction sequence into account in this structural analysis model. Thus, the actual condition on which the r^{th} floor is placed in the building can be adequately modeled.

Using the preceding model, the equilibrium equation to be solved for the typical rth floor is written as

$$K^r U^r = P^r \qquad \text{Eq. (2.1)}$$

Where,

K^r = the assembled stiffness matrix of the frame between the ground floor and the rth floor;

$$K^r = \sum_{m=1}^{r} K^{(m)} \qquad \text{Eq. (2.1a)}$$

Where,

$K^{(m)}$ = the stiffness matrix of the typical m^{th} floor;

P^r = the load vectors comprising the loads from the floors above and the weight of the rth floor and;

U^r = the nodal displacement vector.

Once the behaviour of the r^{th} floor is obtained, the floor immediately below it [i.e., the $(r - l)^{th}$ floor] becomes active and so on. The entire behaviour of the frame can be obtained by a "one floor at a time" fashion as the active floor moves from top down to the bottom of the building. It should be more convenient to proceed with the analysis in the preceding sequence, which is the reverse order of construction sequence. For an example, the top floor (n^{th} floor) is analyzed with only its own weight by the aforementioned model, the top floor being active and the rest of the frame inactive. When the displacements of the n^{th} floor are obtained, the member forces are calculated based on them. Then, the column forces are saved for later use as the "loads from upper floors" to be applied on the next floor. As the analysis proceeds, the active floor comes down a floor at an analysis cycle until the last floor (ground floor) is analyzed. Considering the construction sequence of one

floor at a time, *n* analyses are required for the analysis of a frame of *n* stories. To reduce the computational efforts, the sub structuring technique can be utilized. Instead of a floor-by-floor analysis, the entire structure is now more efficiently analyzed by the substructure-by-substructure approach with the concepts of active, inactive, and deactivated substructures, as shown in figure 2.2. Thus, a group of floors in an active substructure are activated at once in the final frame analysis model.

2.3.1 Analysis by Sub-structuring

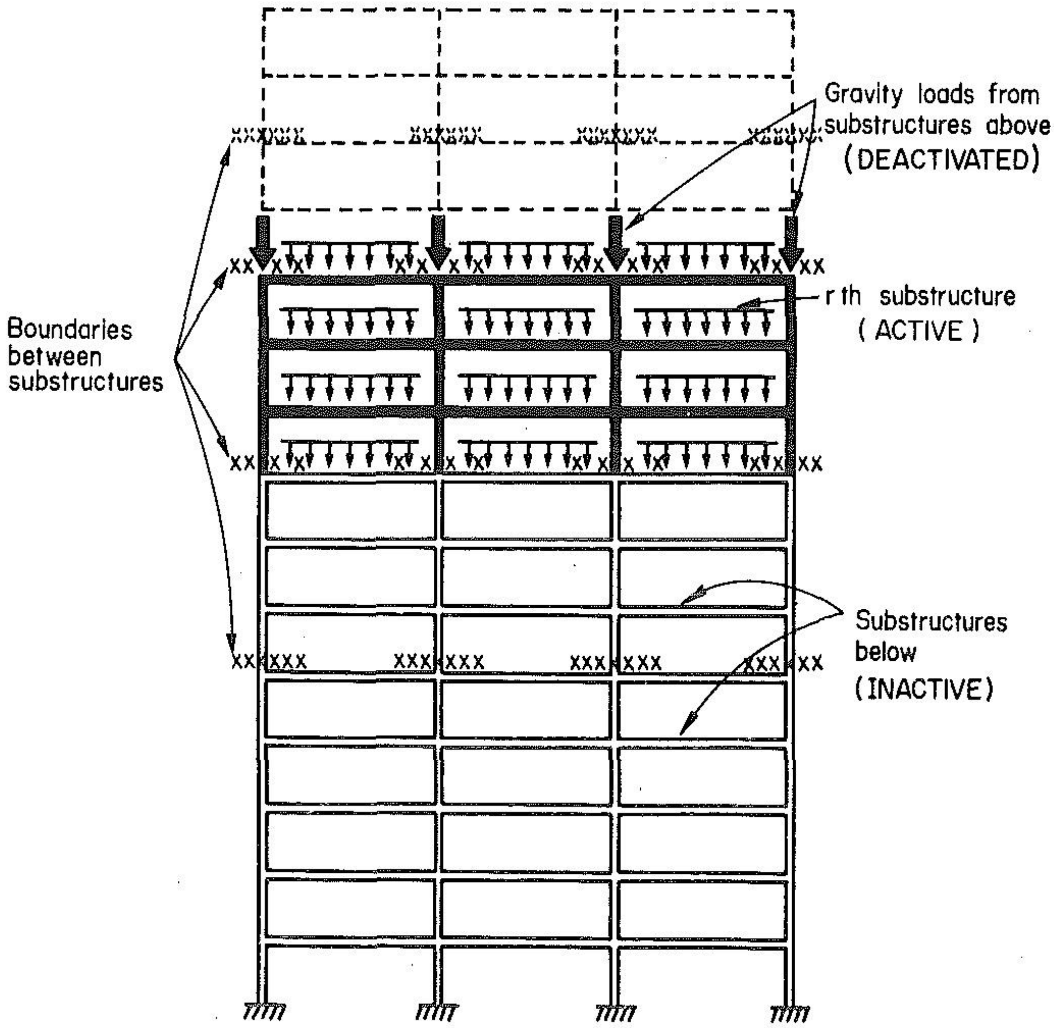

Figure 2.2 Sub-structure arrangement for frame analysis

With the structural partitioning, a multistorey building frame is divided into a number of substructures interconnected at the interior boundaries *(Figure 2.2).* The basis for the static analysis of structures using sub-structuring is given by Przemieniecki 1968 and; Rosen and Rubinstein 1970. The theoretical considerations are not repeated herein. For the analysis of the r^{th} substructure which is active at this analysis cycle, the frame above it is modelled as external loads, and the substructures below it are considered weightless elastic supports as before *(Figure 2.2)*. The intensities of these loads from substructures above are computed as the reactions along the boundaries between the rth and $(r + l)^{th}$ sub-structures in the previous analysis. In this scheme, the displacements along the boundaries are obtained first, and then the internal displacements of an active substructure are computed later. It is also noted that using the variable sizes of substructures, i.e., using progressively larger segments of the structure may be more effective than using uniform sizes.

2.4 Correction Factor Method (CFM)

The methods discussed previously to handle the problems associated with the segmental application of dead loads give accurate results with some increase of computational efforts once the computer codes are developed. In the practical application of these methods, however, practicing engineers may need to know about the nature of problems involved, and algorithms and their computer implementations for proper utilization of the schemes. In order to enhance the increased use of correction techniques among the practitioners, a simplified yet reasonably reliable method needs to be developed.

The erroneous stresses and displacements of the ordinary analysis are induced by the combined effects of the erroneous differential column shortenings and joint rotations. To obtain the correct stresses and displacements in the frame analysis by excluding these erroneous values, a step-by-step analysis for each stage of construction was carried out with some success (Choi and Kim 1985; Saffarini and Wilson 1983). Instead of carrying out the elaborate repetitive analysis, an approach that modifies the finite element analysis solution by adding or subtracting the

correction forces calculated by the use of correction factors should be more effective to obtain an improved solution. The correction factors can be obtained by the curve to be established statistically from the results of existing building analyses, whose basic concept is similar to the design response spectrum for seismic design. To establish a correction factor curve, a number of buildings with various number of floors and members of various sizes are analyzed by two different methods:

1) The conventional finite element analysis of the structure as a whole where the effects of sequential application of dead loads are not considered (method A).
2) The analysis of the structure considering the sequential application of dead loads such as the analysis by the method discussed earlier (Choi and Kim 1985) (method B).

The basic conceptual sketches are given in figures 2.3 (a) and 2.3 (b), where the differential column shortenings for the bays and floors of each building are calculated by two different methods and plotted along with the building heights. Based on the fact that the analysis by method B represents the real behavior of the structure more closely, the difference between two curves (δ_A^i - δ_B^i) is defined as "the erroneous differential column shortening" included in the solutions by the ordinary analysis. The difference, however, is nonexistent in the reality as discussed in Choi and Kim (1985). The erroneous differential column shortening is then normalized with maximum value at the top floor to form a single curve *(Figure 2.3)*. The normalized curves that represent different frames are assembled in a single figure to show the general trends of variations *[Figure 2.4 (a)]*. The curves of the mean values and the mean plus/minus the standard deviation can be formed in the figure, and the equations of the curves can be determined by regression *[Figure 2.4 (b)]*.

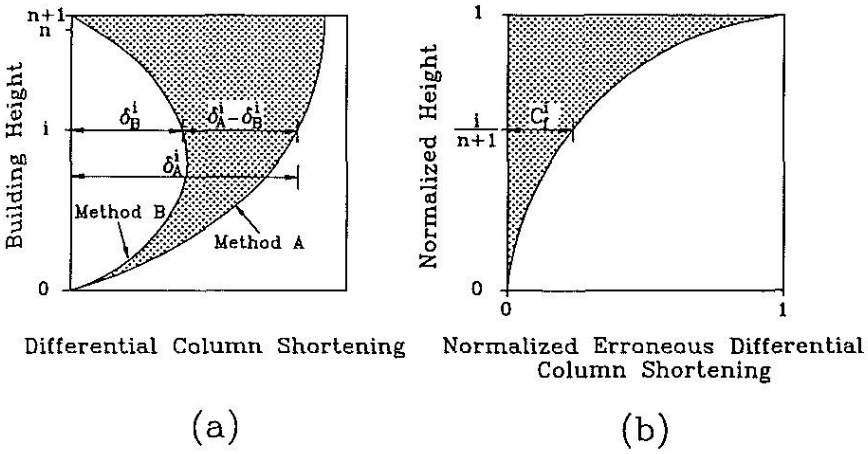

Figure 2.3 Calculation of Correction Factor for Normalized Curves: (a) Erroneous Differential Column shortening; and (b) Correction Factor for ith Floor

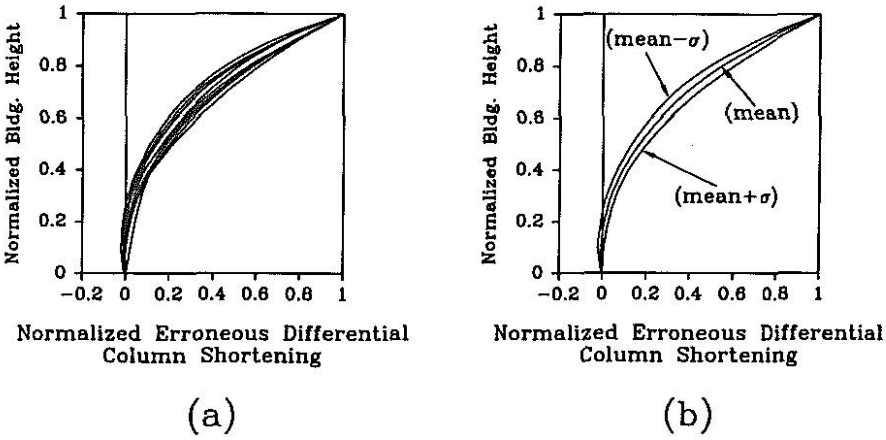

Figure 2.4 Regression of Erroneous Differential Column Shortening: (a) Assembled Normalized Curves; and (b) Mean and Mean ± σ Curves

The correction factor for i[th] floorC_f^i, that is the ratio of the erroneous differential column shortening of i[th] floor to that of the top floor, is defined by the following equation:

$$C_f^i = \frac{\delta_A^i - \delta_B^i}{\delta_A^n} \qquad \text{Eq. (2.2)}$$

Where,

δ = the differential column shortening;

Subscripts A and B = the methods of analysis and;

i and n = ith and nth (top) floor, respectively.

The erroneous differential column shortening for ith floor δ_e^i can be calculated approximately by the use of correction coefficient C_f^i.

$$\delta_e^i = \delta_A^i - \delta_B^i \approx \delta_A^n \times C_f^i \qquad \text{Eq. (2.3)}$$

The amounts of the corrections needed for member end moments M_c^i and shear forces S_c^i of beams on ith floor can be calculated as the moments and shears induced in the beams by the erroneous differential settlements based on the basic elastic theory.

$$M_c^i = \frac{6EI}{L^2(1+2\beta)} \times \delta_e^i \qquad \text{Eq. (2.4a)}$$

$$S_c^i = \frac{12EI}{L^3(1+2\beta)} \times \delta_e^i \qquad \text{Eq. (2.4b)}$$

Where,

$$\beta = \frac{6EI}{L^2AG} \times \delta_e^i \qquad \text{Eq. (2.4c)}$$

L = the length of beam and;

E, I, A and β denote Young's modulus, the moment of inertia, the effective shear area, and the shear flexibility factor, respectively.

Once the correction forces (M_c and S_c) in each beam are determined, these are combined with the results obtained by the ordinary analysis to form the final solutions.

$$M_f^i = M_0^i - M_c^i \qquad \text{Eq. (2.5a)}$$

$$S_f^i = S_0^i - S_c^i \qquad \text{Eq. (2.5b)}$$

Where,

M_f and S_f = the final (corrected) bending moments and shear forces, respectively and;

M_0 and S_0 = the bending moments and shear forces from the ordinary analysis, respectively.

The moments in columns are also corrected in the same manner. The amount of correction forces are determined based on the equilibrium of the correction forces at each joint where beams and columns are connected together.

2.5 Conclusion

With the above discussion it is clear that very less attention has been paid on the effect of instability of incomplete structure and the variation of loads during construction. Therefore, this paper deals with the responses of various forces in terms of axial forces, bending moments, shear forces and twisting moments induced in the members of a RC building.

Chapter 3. SYSTEM DEVELOPMENT

3.1 General

In this project several models of G+5 and G+7 RC buildings frames with 4 bays along length and width are analyzed using STAAD*pro*. Various stiffness governing factors such as bay width/length, storey height, etc. are decided as basic parameters. Six frames of five storied and seven storied RC buildings of bay width/length 4m, 5m and 6m and storey height 3m was modeled and analyzed with conventional method and by Construction Stage Analysis. Then three frames of five storied RC building of storey height 4m and bay width/length 4m, 5m, and 6m was also analyzed by both the methods. These nine models were used for the comparison of responses of various forces in terms of axial forces, bending moments, shear forces and twisting moments. Figure 3.1 shows the typical floor plan of the models.

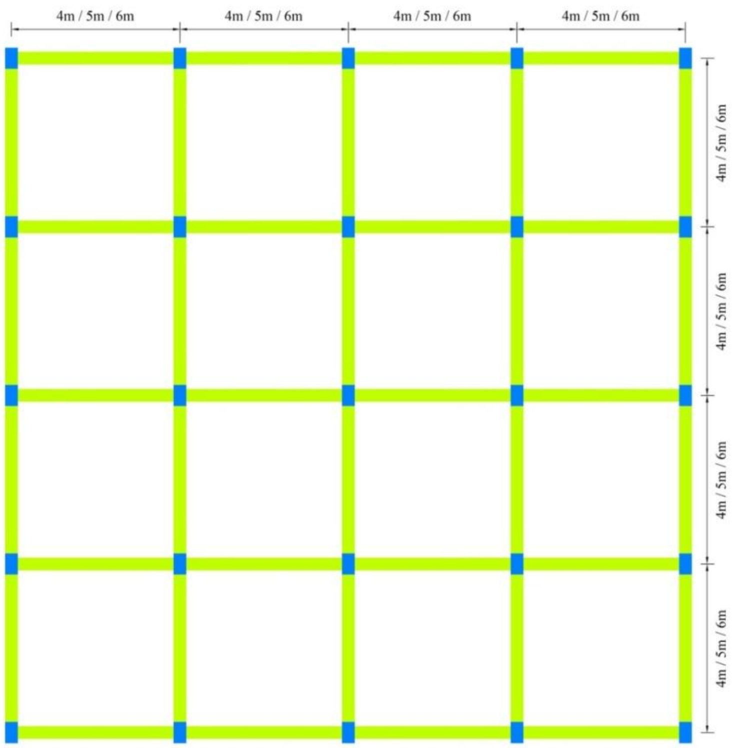

Figure 3.1 Typical Floor Plan

The summary of member sizes for G+5 and G+7 with storey height of 3m and 4m is shown in Table 1 below.

Table 3.1 Summary of Member Sizes

Bay Width/Length	4 m	5 m	6 m
Column Size (m x m)	0.23 x 0.60	0.30 x 0.60	0.30 x 0.75
Beam Size (m x m)	0.23 x 0.45	0.30 x 0.60	0.30 x 0.60
Slab Thickness (mm)	150	150	200

3.2 Construction Stage Analysis

Consider a typical floor (say *C*) of a frame shown in figure 3.2(b). Assuming the building is constructed one floor at a time, the *C* floor is constructed on the top of the frame that was completed so far [i.e., up to *(C - 1)* floor]. The slab of *(C-1)* floor supports the selfweight of freshly poured *C* floor slab by the formwork in addition to its own selfweight. Also the construction live load on *C* floor equal to the inspection live load on *(C-1)* floor will be transferred to the slab of *(C-1)* floor. Figure 3.2(b) clearly illustrates how the loads transfers on the frame in construction stage analysis.

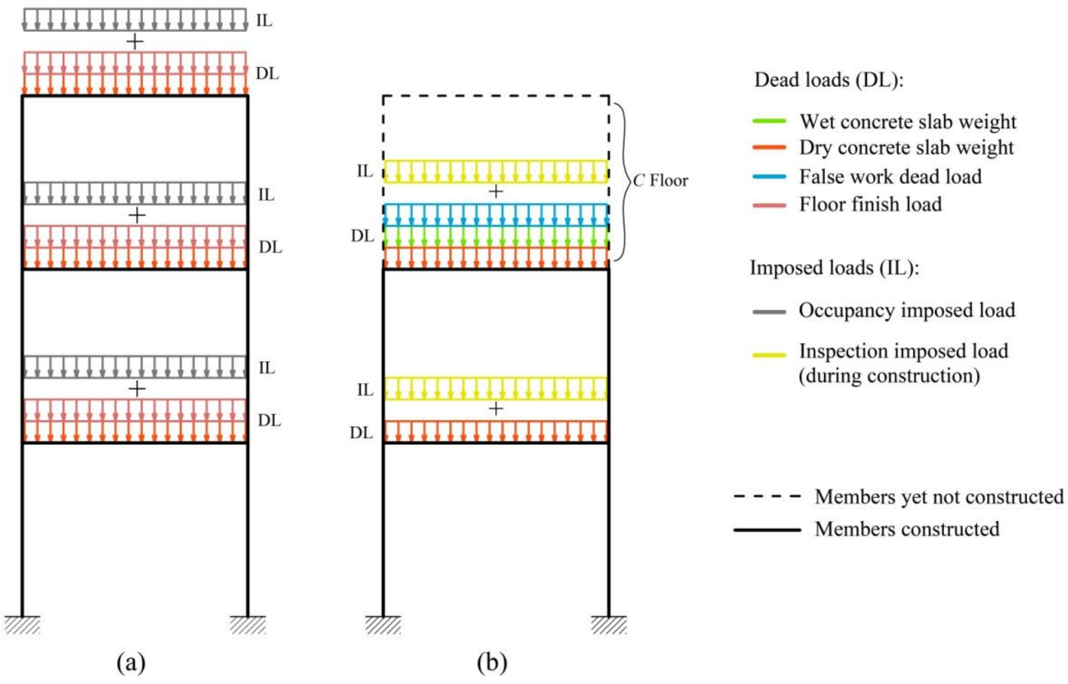

Figure 3.2 (a) Conventional Analysis; (b) Construction Stage Analysis.

3.2.1 Loadings

Load Cases:

1) *Dead Loads:*
    - i) Selfweight of columns and beams;
    - ii) Selfweight of wet concrete slab (weight density = 25 KN/m^3);
    - iii) Selfweight of dry concrete slab (freshly poured) [weight density = 26 KN/m^3 (refer IS 14687 : 1999)];
    - iv) False work dead load [500 N/m^2 (refer IS 14687 : 1999)].
2) *Imposed Loads:*
    - i) Inspection live load on *C* floor slab [750 N/m^2 (refer IS 14687 : 1999)]
    - ii) Construction live load on *(C+1)* floor slab [assumed adequate to be equal to inspection live load i.e. 750 N/m^2 (refer IS 14687 : 1999)]

Load Combinations:

1) 1.5 times dead loads and imposed loads [i.e. 1.5(DL+LL)].

3.3 Conventional Analysis

As illustrated in figure 3.2(a), all the probable loads was applied after modeling the entire frame.

3.3.1 Loadings

Without Earthquake Forces:

Load Cases:

1) *Dead Loads:*
    - i) Selfweight of columns and beams;
    - ii) Selfweight of wet concrete slab (weight density = 25 KN/m^3);
    - iii) Floor finish load (assumed 1 KN/m^2).
2) *Imposed Loads:*
    - i) Occupancy live load on *C* floor slab [2.5 KN/m^2 (refer IS 875 : 1987)].

Load Combinations:

1) 1.5 times dead loads and imposed loads [i.e. 1.5(DL+LL)].

With Earthquake Forces:

Seismic Definitions:

1) Zone:	0.1 (Zone II)
2) Response reduction Factor (RF):	5
3) Importance factor (I):	1
4) Rock and soil site factor (SS):	1
5) Type of structure:	1 (RC Frame Building)
6) Damping ratio (DM):	5

Load Cases:

1) *Earthquake forces in X-Direction* (EQx)
2) *Earthquake forces in Z-Direction* (EQz)
3) *Dead Loads* (DL):
   i) Selfweight of columns and beams;
   ii) Selfweight of wet concrete slab (weight density = 25 KN/m^3);
   iii) Floor finish load (assumed 1 KN/m^2).
4) *Reducible Imposed Loads* (LL/rLL):
   i) Occupancy live load [2.5 KN/m^2 (refer IS 875 : 1987)].

Load Combinations (refer IS 1893 : 2002):

1) 1.5(DL+LL);
2) 1.2(DL+rLL+EQx);
3) 1.2(DL+rLL-EQx);
4) 1.2(DL+rLL+EQz);
5) 1.2(DL+rLL-EQz);
6) 1.5(DL+EQx);
7) 1.5(DL-EQx);
8) 1.5(DL+EQz);
9) 1.5(DL-EQz);
10) 0.9DL+1.5EQx;
11) 15 0.9DL-1.5EQx;
12) 0.9DL+1.5EQz;
13) 0.9DL-1.5EQz.

Chapter 4. PERFORMANCE ANALYSIS

4.1 General

Several numbers of G+5 and G+7 reinforced concrete building frames of different sizes were analyzed using STAAD*pro*. The results obtained were compared with construction stage model. Then all full frame models were analyzed for earthquake forces in Zone–II in accordance with IS 1893:2002. Note that earthquake forces were not considered for analyzing the construction stage models. The results of construction stage model were compared with conventional analysis considering earthquake forces.

4.2 Results

4.2.1 Comparison Tables

NOTE: Negative sign indicates % decrease in response and % positive sign indicates increase in response.

CSA: Construction Stage Analysis

CA: Conventional Analysis (without earthquake forces)

CA (Eq.): Conventional Analysis (with earthquake forces)

Table 4.1 First floor of G+5 (3m storey height)

		Percent Difference (%)					
		CSA vs CA			**CA (Eq.) vs CSA**		
Bay Width/Length		**4 m**	**5 m**	**6 m**	**4 m**	**5 m**	**6 m**
Beams							
Edge Beams:							
Bending (Mz)	Positive	-15.23	-7.25	10.1	17.97	25.98	-9.17
	Negative	-20.42	-10.86	6.29	48.94	87.03	2.28
Shear	Fy	-28.27	-21.43	-4.89	41.77	49.6	5.14
Torsion	Mx	116.39	148.18	132.55	-54.55	-59.71	-57

		Percent Difference (%)					
		CSA vs CA			**CA (Eq.) vs CSA**		
Bay Width/Length		**4 m**	**5 m**	**6 m**	**4 m**	**5 m**	**6 m**
Interior Beams							
Bending (Mz)	Positive	11.65	17.45	33.39	-10.44	-14.86	-25.04
	Negative	7.75	16.47	32.55	-3.27	20.68	-24.55
Shear	Fy	0.49	5.54	21.67	-0.48	-1.58	-17.81
Torsion	Mx	900	1100	755.56	-70	0	-66.23
Columns							
Corner Columns							
Axial	Fx	-87.51	-86.44	-78.39	700.77	637.54	561.14
Bending Moments	Mz	12.44	33.1	53.31	14.01	61.53	-31.95
	My	-17.97	11.31	19.13	98.23	99.15	11.5
Shear Forces	Fy	-14.79	0.89	14.9	68.9	117.26	10.88
	Fz	-31.3	-8.69	-0.21	160.49	176.67	46.58
Edge Columns							
Axial	Fx	-85.55	-84.57	-82.46	592.16	548.07	470.17
Bending Moments	Mz	56.11	76.98	93.34	-32.76	-1.98	-48.28
	My	12.99	46.77	50.63	25.74	25.23	-21.52
Shear Forces	Fy	25.65	43.19	54.82	4.96	40.03	-23.33
	Fz	-1.54	26.54	32.46	63.61	78.41	0.58
Interior Columns							
Axial	Fx	-82.22	-81.63	-79.23	462.36	444.48	381.43
Bending Moments	Mz	23.62	186.53	176.31	436.65	849.47	135.46
	My	1654.1	1735.4	823.66	399.07	664.47	58.91
Shear Forces	Fy	20	203.85	204.44	495.1	852.74	113.98
	Fz	57.89	2341.2	1160	606	948.19	202.81

Table 4.2 Second floor of G+5 (3m storey height)

		Percent Difference (%)					
		CSA vs CA			CA (Eq.) vs CSA		
Bay Width/Length		**4 m**	**5 m**	**6 m**	**4 m**	**5 m**	**6 m**
Beams							
Edge Beams							
Bending (Mz)	Positive	-15.08	-7.14	10.52	17.76	20.49	-9.51
	Negative	-29.37	-16.95	0.37	62.57	88.96	4.31
Shear	Fy	-29.94	-22.14	-4.1	42.73	47.96	4.29
Torsion	Mx	131.58	180.65	152.11	-56.82	-64.37	-60.33
Interior Beams							
Bending (Mz)	Positive	12.43	18.12	34.59	-11.05	-15.34	-25.7
	Negative	-5.49	7.15	23.39	6.93	25.89	-18.95
Shear	Fy	-2.55	4.16	22.14	2.61	-2.59	-18.12
Torsion	Mx	275	366.67	530	-53.33	53.57	-49.21
Columns							
Corner Columns							
Axial	Fx	-84.74	-83.47	-81.64	555.51	504.9	444.52
Bending Moments	Mz	2.2	17.45	36.01	15.62	40.94	-21.2
	My	-23.81	-1.19	5.76	88.93	90.54	13
Shear Forces	Fy	-23.74	-12.36	-1.65	54.98	87.83	8.92
	Fz	-35.79	-19.67	-12.49	123.51	135.87	37.48
Edge Columns							
Axial	Fx	-82.54	-81.31	-78.85	472.5	435.05	372.8
Bending Moments	Mz	32.65	47.04	63.72	-21.78	-3.48	-38.92
	My	-0.69	22.2	25.69	24.02	27.85	-15.8
Shear Forces	Fy	-0.05	10.05	17.46	3.83	28.08	-14.87
	Fz	-16.81	-0.48	3.27	47.91	59.09	3.1
Interior Columns							
Axial	Fx	-78.73	-78	-75.1	370.26	354.53	301.64
Bending Moments	Mz	-62.21	37.07	73.5	926.67	1026.7	162.08
	My	320.9	1196.7	534.51	465.25	744.73	135.97

		Percent Difference (%)					
		CSA vs CA			CA (Eq.) vs CSA		
Bay Width/Length		**4 m**	**5 m**	**6 m**	**4 m**	**5 m**	**6 m**
Shear Forces	Fy	-96.76	33.21	82.48	13180	1227.5	196.9
	Fz	453.85	3800	665.45	628.47	1017.7	197.27

Table 4.3 Third floor of G+5 (3m storey height)

		Percent Difference (%)					
		CSA vs CA			CA (Eq.) vs CSA		
Bay Width/Length		**4 m**	**5 m**	**6 m**	**4 m**	**5 m**	**6 m**
Beams							
Edge Beams							
Bending (Mz)	Positive	-14.81	-6.96	10.68	17.39	13.35	-9.65
	Negative	-35.19	-21.46	-5.67	69.02	87.38	7.61
Shear	Fy	-32.14	-23.73	-6.31	47.37	43.61	6.73
Torsion	Mx	127.87	171	24700	-56.12	-63.1	-59.27
Interior Beams							
Bending (Mz)	Positive	12.68	18.23	34.65	-11.26	-15.42	-25.74
	Negative	-13.56	1.04	15.57	14	26.34	-13.47
Shear	Fy	-5.89	1.8	19.04	21.07	-1.77	-15.99
Torsion	Mx	100	200	375	-33.33	87.5	-43.86
Columns							
Corner Columns							
Axial	Fx	-80.51	-78.96	-76.65	413.09	375.22	328.35
Bending Moments	Mz	2.71	20.8	38.43	13.84	36.72	-22.78
	My	-23.63	0.98	6.9	79.14	82.31	9.92
Shear Forces	Fy	-23.39	-12.08	-2.05	48.8	78.34	6.53
	Fz	-35.47	-19.25	-12.39	111.33	124.44	33.49
Edge Columns							
Axial	Fx	-77.84	-76.28	-73.3	351.17	321.6	274.47
Bending Moments	Mz	36.39	53.85	68.3	-24.63	-7.89	-40.58
	My	-0.22	26.59	28.15	18.63	22.98	-18.27

		Percent Difference (%)					
		CSA vs CA			CA (Eq.) vs CSA		
Bay Width/Length		**4 m**	**5 m**	**6 m**	**4 m**	**5 m**	**6 m**
Shear Forces	Fy	1.04	11.16	17.19	-0.31	22.53	-13.51
	Fz	-16.11	0.87	3.93	40.88	52.76	0.47
Interior Columns							
Axial	Fx	-73.32	-72.21	-68.72	274.79	259.85	219.66
Bending Moments	Mz	-85.49	-54.58	-37.28	1835.7	1899.5	367.65
	My	7.03	130.15	345.07	698.99	920.61	165.78
Shear Forces	Fy	-89.11	-66.99	-48.35	2464.8	2598.3	458.03
	Fz	-25.44	65.09	259.44	1125.9	1405.4	265.07

Table 4.4 Fourth floor of G+5 (3m storey height)

		Percent Difference (%)					
		CSA vs CA			CA (Eq.) vs CSA		
Bay Width/Length		**4 m**	**5 m**	**6 m**	**4 m**	**5 m**	**6 m**
Beams							
Edge Beams							
Bending (Mz)	Positive	-14.45	-6.91	10.85	16.89	7.42	-9.79
	Negative	-39.98	-25.32	-10.62	71.36	78.27	11.88
Shear	Fy	-34.04	-25.19	-8.21	51.61	39.63	8.94
Torsion	Mx	128.13	170.87	144.98	-56.16	-63.08	-59.18
Interior Beams							
Bending (Mz)	Positive	13.02	18.22	34.79	-11.55	-15.42	-25.81
	Negative	-20.05	-4.09	9.31	25.07	21.89	-8.52
Shear	Fy	-8.73	-0.31	16.42	9.56	0.31	-14.1
Torsion	Mx	0	-30	193.75	0	514.29	-38.3
Columns							
Corner Columns							
Axial	Fx	-73.03	-71.05	-67.98	270.84	245.45	212.29
Bending Moments	Mz	4.79	22.16	39.99	8.35	31.31	-24.65
	My	-21.96	1.43	7.56	62.67	67.02	4.02

		Percent Difference (%)					
		CSA vs CA			CA (Eq.) vs CSA		
Bay Width/Length		**4 m**	**5 m**	**6 m**	**4 m**	**5 m**	**6 m**
Shear Forces	Fy	-21.65	-11.04	-0.95	37.45	61.88	1.53
	Fz	-33.76	-18.49	-11.53	89.53	101.01	25.01
Edge Columns							
Axial	Fx	-69.64	-67.72	-63.58	229.39	209.76	174.6
Bending Moments	Mz	38.72	55.23	69.9	-27.69	-10.46	-41.14
	My	1.42	26.74	28.48	9.38	14.68	-21.65
Shear Forces	Fy	3.06	12.27	18.41	-2.96	12.93	-15.55
	Fz	-14.3	1.4	4.6	28.21	39.42	-4.4
Interior Columns							
Axial	Fx	-63.75	-62.5	-58.01	175.86	166.66	138.17
Bending Moments	Mz	-67.37	-90.21	-75.77	625.34	7744.3	931.28
	My	-57.59	32.32	134.6	1224.8	1110.4	198.47
Shear Forces	Fy	-67.47	-95.6	-79.64	587.89	15915	1040.9
	Fz	-82.93	-17.75	66.78	3275	1877.4	335.21

Table 4.5 Fifth floor of G+5 (3m storey height)

		Percent Difference (%)					
		CSA vs CA			CA (Eq.) vs CSA		
Bay Width/Length		**4 m**	**5 m**	**6 m**	**4 m**	**5 m**	**6 m**
Beams							
Edge Beams							
Bending (Mz)	Positive	-13.47	-5.74	12.3	15.56	6.09	-10.95
	Negative	-44.02	-28.63	-13.89	78.74	61.95	16.13
Shear	Fy	-35.64	-26.39	-9.4	55.38	35.85	10.37
Torsion	Mx	142.86	200	161.39	-58.82	-66.67	-61.74
Interior Beams							
Bending (Mz)	Positive	14.42	19.88	36.7	-12.6	-16.58	-26.84
	Negative	-25.54	-8.53	5.17	34.29	12.35	-4.92
Shear	Fy	-11.05	-2.05	14.81	12.43	2.09	-12.9

		Percent Difference (%)					
		CSA vs CA			CA (Eq.) vs CSA		
Bay Width/Length		**4 m**	**5 m**	**6 m**	**4 m**	**5 m**	**6 m**
Torsion	Mx	-10	-13.33	54.17	11.11	184.62	-27.03
Columns							
Corner Columns							
Axial	Fx	-56.58	-53.83	-49.25	130.32	116.61	97.06
Bending Moments	Mz	8.65	24.44	38.76	0.03	21.1	-26.47
	My	-17.89	5.33	11.42	41.04	44.24	-5.75
Shear Forces	Fy	-18.34	-8.73	-0.63	23.3	40.68	0.61
	Fz	-30.17	-14.98	-8.14	61.87	68.94	12.35
Edge Columns							
Axial	Fx	-51.77	-49.09	-43.14	107.34	96.43	75.86
Bending Moments	Mz	43.58	57.86	68.47	-30.33	-16.39	-40.64
	My	6.59	31.57	32.81	-3.82	0.73	-24.71
Shear Forces	Fy	7.55	15.35	18.64	-7.02	-0.37	-15.71
	Fz	-9.94	6.05	8.52	11.32	19.6	-7.85
Interior Columns							
Axial	Fx	-43.11	-41.66	-35.23	75.78	71.42	54.39
Bending Moments	Mz	-48.36	-80.11	-91.68	243.82	2317	1961.2
	My	-60.99	-43.5	9.36	824.6	1480.7	243.77
Shear Forces	Fy	-50.63	-79.05	-92.1	227.71	1950.3	1928.9
	Fz	-80.29	-77.18	-33.84	1739	3839.5	485.02

Table 4.6 First floor of G+7 (3m storey height)

		Percent Difference (%)					
		CSA vs CA			CA (Eq.) vs CSA		
Bay Width/Length		**4 m**	**5 m**	**6 m**	**4 m**	**5 m**	**6 m**
Beams							
Edge Beams							
Bending (Mz)	Positive	-15.35	29.84	10.01	20.69	-15.49	1.66
	Negative	-23.31	24.66	6.39	57.74	17.2	6.04

		Percent Difference (%)					
		CSA vs CA			CA (Eq.) vs CSA		
Bay Width/Length		**4 m**	**5 m**	**6 m**	**4 m**	**5 m**	**6 m**
Shear	Fy	-27.53	8.48	-4.02	42.2	-5.44	8.5
Torsion	Mx	3225	222.43	127.19	-52.63	-68.99	-33.87
Interior Beams							
Bending (Mz)	Positive	11.57	68.72	33.3	-8.95	-40.03	-16.69
	Negative	3.74	67.6	31.86	1.3	-26.82	-23.58
Shear	Fy	1.33	51.08	22.81	-1.31	-36.16	-15.19
Torsion	Mx	566.67	1300	1183.3	-80	-71.43	-71.43
Columns							
Corner Columns							
Axial	Fx	-91.14	-87.89	-89.14	1028.9	725.43	794.71
Bending Moments	Mz	8.73	79.47	48.96	22.09	-0.38	-27.59
	My	-21.16	33.74	15.75	109.6	56.52	4.26
Shear Forces	Fy	-17.48	33.3	11.72	78.62	40.82	16.68
	Fz	-33.88	9.85	-2.8	175.61	117.39	38.56
Edge Columns							
Axial	Fx	-89.54	-84.92	-87.19	803.33	538.88	678.33
Bending Moments	Mz	50.73	146.91	87.71	-30.52	-43.41	-46.85
	My	8.55	83.39	45.95	31.73	-3.94	-30.5
Shear Forces	Fy	21.07	97.71	49.85	9.56	-14.77	-19.2
	Fz	-5.5	58.96	28.06	71.67	31.21	-9.02
Interior Columns							
Axial	Fx	-86.8	-80.9	-84.53	624.9	409.47	541.5
Bending Momemts	Mz	-8.17	184.36	99.51	487.43	409.75	148.37
	My	417.74	1234.6	1393.9	449.53	372.43	116.47
Shear Forces	Fy	-11.3	194.69	115.93	552.45	413.96	165.52
	Fz	294.74	1765.4	2541.9	680.67	554.23	201.22

Table 4.7 Second floor of G+7 (3m storey height)

		Percent Difference (%)					
		CSA vs CA			CA (Eq.) vs CSA		
Bay Width/Length		**4 m**	**5 m**	**6 m**	**4 m**	**5 m**	**6 m**
Beams							
Edge Beams							
Bending (Mz)	Positive	-15.2	-0.72	10.37	20.29	8.41	2.09
	Negative	-33.09	-15.05	-4.09	75.61	64.38	13.57
Shear	Fy	-31.48	-17.38	-5.82	45.95	28.89	7.26
Torsion	Mx	123.73	267.71	140.91	-55.3	-72.8	-32.29
Interior Beams							
Bending (Mz)	Positive	12.28	24.23	34.33	-9.64	-18.67	-16.65
	Negative	-10.56	8.01	17.74	14.07	10.41	-12.89
Shear	Fy	-4.78	8.06	19.76	5.02	-7.46	-15.4
Torsion	Mx	150	860	376.92	-60	-58.33	-50
Columns							
Corner Columns							
Axial	Fx	-89.76	-88.92	-87.52	876.06	802.9	675.3
Bending Moments	Mz	-2.6	13.69	31.71	25.23	29.66	-16.07
	My	-28.04	-19.69	2	101.63	125.46	5.53
Shear Forces	Fy	-27.09	-13.8	-5.09	65.02	67.24	16.21
	Fz	-39.08	-32.18	-15.84	139.19	167.95	27.82
Edge Columns							
Axial	Fx	-88.05	-86.81	-85.36	684.18	626.45	583.09
Bending Moments	Mz	27.43	40.2	58.73	-17.25	-10.82	-36.02
	My	-5.71	-2.9	21.96	30.91	52.05	-26.49
Shear Forces	Fy	-4.42	6.65	14.36	9.01	14.93	-10.72
	Fz	-20.87	-18.03	0.53	56.43	82.08	-10.39
Interior Columns							
Axial	Fx	-85.02	-84.01	-82.43	534.66	506.03	465.64
Bending Moments	Mz	-72.16	-10.74	15.45	1055.6	828.83	212.56
	My	63.01	696.1	649.07	546.45	734.91	132.88

		Percent Difference (%)					
		CSA vs CA			CA (Eq.) vs CSA		
Bay Width/Length		**4 m**	**5 m**	**6 m**	**4 m**	**5 m**	**6 m**
Shear Forces	Fy	-97.64	7784.1	18.13	14920	-88.34	250.75
	Fz	58.24	1510	1145.6	732.64	892.55	191.97

Table 4.8 Third floor of G+7 (3m storey height)

		Percent Difference (%)					
		CSA vs CA			CA (Eq.) vs CSA		
Bay Width/Length		**4 m**	**5 m**	**6 m**	**4 m**	**5 m**	**6 m**
Beams							
Edge Beams							
Bending (Mz)	Positive	-15.03	-7.76	10.47	20.15	13.88	2.45
	Negative	-39.65	-24.23	-11.14	87.55	77.21	20.33
Shear	Fy	-34.13	-24.25	-8.55	51.81	38.57	10.89
Torsion	Mx	113.85	-94.17	132.39	-53.24	516.67	-29.7
Interior Beams							
Bending (Mz)	Positive	12.39	18.21	34.33	-9.7	-14.48	-16.34
	Negative	-19.54	-1.85	8.64	24.29	17.41	-4.7
Shear	Fy	-8.82	2.18	15.92	9.67	-2.13	-12.19
Torsion	Mx	33.33	262.5	161.9	-25	-27.59	-38.18
Columns							
Corner Columns							
Axial	Fx	-87.92	-87.35	-85.34	727.25	690.24	560.59
Bending Moments	Mz	-3.83	13.13	30.99	21.55	24.67	-16.66
	My	-29.29	-14.77	0.79	94.77	104.8	4.67
Shear Forces	Fy	-28.07	-17.82	-6.97	61.78	69.54	16.44
	Fz	-40.07	-29.61	-17.11	130.8	148.34	27.59
Edge Columns							
Axial	Fx	-85.94	-85.07	-82.88	564.65	541.03	484.07
Bending Moments	Mz	27.65	45.91	59.42	-20.46	-17.57	-35.24
	My	-7.25	8.46	21.62	27.42	33.65	-26.42

		Percent Difference (%)					
		CSA vs CA			CA (Eq.) vs CSA		
Bay Width/Length		**4 m**	**5 m**	**6 m**	**4 m**	**5 m**	**6 m**
Shear Forces	Fy	-5.17	5.35	12.24	6.93	13.47	-8.35
	Fz	-21.81	-10.76	-0.48	51.87	62.85	-9.86
Interior Columns							
Axial	Fx	-82.57	-81.87	-79.52	443.95	433.68	385.86
Bending Moments	Mz	-89.21	-67.6	-56.91	2134.8	1514.6	489.44
	My	-41.07	147.66	89.41	835.35	721.65	179.79
Shear Forces	Fy	-91.72	-76.34	-64.23	2876.4	2151.2	618.64
	Fz	-59.52	96.45	47.71	1214.1	998.92	284.63

Table 4.9 Fourth floor of G+7 (3m storey height)

		Percent Difference (%)					
		CSA vs CA			CA (Eq.) vs CSA		
Bay Width/Length		**4 m**	**5 m**	**6 m**	**4 m**	**5 m**	**6 m**
Beams							
Edge Beams							
Bending (Mz)	Positive	-14.69	-7.5	10.7	19.71	9.96	2.66
	Negative	-44.94	-28.61	-16.79	97.05	78.32	25.44
Shear	Fy	-36.43	-25.97	-10.89	57.3	38.58	14.15
Torsion	Mx	111.59	126.17	130.18	-52.74	-55.37	-28.38
Interior Beams							
Bending (Mz)	Positive	15.46	18.42	34.57	-9.97	-14.61	-16.16
	Negative	-26.71	-7.71	1.54	36.44	19.28	2.72
Shear	Fy	-12.22	-0.35	12.72	13.92	0.35	-9.37
Torsion	Mx	-33.33	118.18	60.71	50	-4.17	-17.78
Columns							
Corner Columns							
Axial	Fx	-85.25	-84.55	-82.15	577.38	547.68	442.97
Bending Moments	Mz	-3.75	12.53	30.07	18.46	22.76	-17.03
	My	-28.96	-15.17	0.18	82.99	93.74	1.26

		Percent Difference (%)					
		CSA vs CA			CA (Eq.) vs CSA		
Bay Width/Length		**4 m**	**5 m**	**6 m**	**4 m**	**5 m**	**6 m**
Shear Forces	Fy	-27.72	-18.02	-7.28	54.38	61.59	14.48
	Fz	-39.54	-29.76	-17.38	114.69	132.53	22.59
Edge Columns							
Axial	Fx	-82.96	-81.93	-79.33	449.59	428.84	383.68
Bending Moments	Mz	27.42	44.8	57.94	-21.52	-18.31	-34.11
	My	-7.24	7.68	20.6	21.19	27.97	-27.94
Shear Forces	Fy	-4.92	4.83	11.72	5.18	9.22	-6.97
	Fz	-21.42	-11.15	-1.01	43.06	54.45	-12.27
Interior Columns							
Axial	Fx	-79.04	-78.18	-75.49	353.76	342.57	305.48
Bending Moments	Mz	-76.89	-93.41	-86.01	789.76	6442.7	1459.8
	My	-76.1	30	6.76	1579.8	842.62	244.17
Shear Forces	Fy	-76.84	-96.9	-87.84	787.3	1274	1700.4
	Fz	-90.38	-7.76	-24.53	4214.3	1250.9	409.05

Table 4.10 Fifth floor of G+7 (3m storey height)

		Percent Difference (%)					
		CSA vs CA			CA (Eq.) vs CSA		
Bay Width/Length		**4 m**	**5 m**	**6 m**	**4 m**	**5 m**	**6 m**
Beams							
Edge Beams							
Bending (Mz)	Positive	-14.23	-7.34	11.04	19.14	9.69	2.69
	Negative	-49.35	-32.33	-21.6	103.92	75.83	32.61
Shear	Fy	-38.42	-27.49	-12.94	62.39	37.91	17.09
Torsion	Mx	115.49	126.13	130	-53.59	-55.78	-27.98
Interior Beams							
Bending (Mz)	Positive	13.25	18.69	34.92	-10.29	-14.81	-16.11
	Negative	-32.5	-12.63	-12.26	48.15	18.78	19.47
Shear	Fy	-15.07	-2.52	9.96	17.75	2.59	-6.84

		Percent Difference (%)					
		CSA vs CA			CA (Eq.) vs CSA		
Bay Width/Length		**4 m**	**5 m**	**6 m**	**4 m**	**5 m**	**6 m**
Torsion	Mx	-35.71	42.86	0	55.56	10	32.35
Columns							
Corner Columns							
Axial	Fx	-81.09	-80.26	-77.26	428.23	406.86	327.1
Bending Moments	Mz	-2.02	13.4	31.26	13.02	18.01	-19.03
	My	-27.27	-14.29	1.19	67.85	78.35	-4.39
Shear Forces	Fy	-26.11	-17.12	-6.22	44.44	50.72	10.83
	Fz	-37.81	-28.73	-16.26	95.04	111.71	15.06
Edge Columns							
Axial	Fx	-78.4	-77.14	-73.78	331.76	317.01	283.64
Bending Moments	Mz	29.32	45.65	59.03	-22.67	-20.76	-34.1
	My	-5.48	8.52	21.49	12.71	19.52	-30.97
Shear Forces	Fy	-3.06	5.81	12.81	3.16	2.93	-7.22
	Fz	-19.58	-10.15	0.06	31.76	42.81	-16.45
Interior Columns							
Axial	Fx	-73.59	-72.51	-69.23	258.59	250.19	223.75
Bending Moments	Mz	-61.26	-83.89	-89.88	362.01	2135.6	1812.6
	My	-77.34	-26.54	-39.47	1277	1063.9	359.95
Shear Forces	Fy	-63.24	-83.64	-91.15	373.14	1996.4	2041.9
	Fz	-88.61	-57.37	-65.54	2685.4	1877.4	726.57

Table 4.11 Sixth floor of G+7 (3m storey height)

		Percent Difference (%)					
		CSA vs CA			CA (Eq.) vs CSA		
Bay Width/Length		**4 m**	**5 m**	**6 m**	**4 m**	**5 m**	**6 m**
Beams							
Edge Beams							
Bending (Mz)	Positive	-13.84	-7.13	11.27	18.68	9.46	2.62
	Negative	-50.84	-35.62	-25.92	103.42	69.49	40.78

		Percent Difference (%)					
		CSA vs CA			**CA (Eq.) vs CSA**		
Bay Width/Length		**4 m**	**5 m**	**6 m**	**4 m**	**5 m**	**6 m**
Shear	Fy	-40.16	-28.85	-14.82	67.11	40.55	19.87
Torsion	Mx	116.22	127.19	131.22	-53.75	-55.98	-28.47
Interior Beams							
Bending (Mz)	Positive	13.59	18.86	35.11	-10.55	-14.91	-16.12
	Negative	-34.1	-16.9	-9.7	51.74	20.33	-25.67
Shear	Fy	-17.52	-4.46	7.47	21.25	4.66	-4.5
Torsion	Mx	-31.25	0	-17.65	45.45	33.33	85.71
Columns							
Corner Columns							
Axial	Fx	-73.77	-72.75	-68.71	280.94	267.15	210.12
Bending Moments	Mz	1.4	15.98	34.42	5.35	10.38	-22.28
	My	-24.53	-12.56	3.28	49.84	58.85	-12.11
Shear Forces	Fy	-23.35	-15.14	-3.96	32.03	36.46	8.64
	Fz	-35.15	-26.95	-14.13	57.8	86.09	5.01
Edge Columns							
Axial	Fx	-70.39	-68.72	-64.52	214.23	203.52	181.85
Bending Moments	Mz	33.23	48.65	62.56	-24.94	-25.08	-35.26
	My	-2.64	10.28	23.51	2.39	8.33	-35.44
Shear Forces	Fy	0.18	8.16	15.33	-0.18	-5.71	-8.85
	Fz	-16.73	-8.28	2.21	18.49	27.85	-22.38
Interior Columns							
Axial	Fx	-64	-62.92	-58.42	163.21	158.32	140.49
Bending Moments	Mz	-44.65	-64.52	-69.39	185.24	772.94	467.95
	My	-61.78	-61.84	-70.98	543.75	1534.3	654.93
Shear Forces	Fy	-49.28	-67.24	-73.96	192.82	748.49	533.85
	Fz	-71.05	-88.65	-93.76	751.26	5195.2	3430

Table 4.12 Seventh floor of G+7 (3m storey heights)

		Percent Difference (%)					
		CSA vs CA			**CA (Eq.) vs CSA**		
Bay Width/Length		**4 m**	**5 m**	**6 m**	**4 m**	**5 m**	**6 m**
Beams							
Edge Beams							
Bending (Mz)	Positive	-12.75	-6.02	12.93	17.09	8.07	1.8
	Negative	-48.93	-38.5	-28.91	95.83	62.59	47.55
Shear	Fy	-41.79	-29.97	-16.01	71.8	42.8	21.87
Torsion	Mx	131.94	164.36	148.25	-56.89	-58.8	-30.74
Interior Beams							
Bending (Mz)	Positive	15.17	20.47	37.24	-11.78	-16.08	-16.83
	Negative	-32.01	-20.65	-13.28	47.07	26.02	22.07
Shear	Fy	-19.62	-6.06	5.92	24.41	6.45	-2.83
Torsion	Mx	-22.22	-26.32	-21.74	28.57	35.71	66.67
Columns							
Corner Columns							
Axial	Fx	-57.74	-56.33	-49.36	136.48	129.19	95.07
Bending Moments	Mz	5.17	18.41	33.62	-3.43	0.88	-22.96
	My	-19.83	-8.74	7.84	28.9	34.57	-21.91
Shear Forces	Fy	-19.82	-12.77	-3.2	24.72	20.82	7.02
	Fz	-31.08	-23.5	-9.97	46.82	55.33	-7.33
Edge Columns							
Axial	Fx	-52.98	-50.55	-44.39	97.29	91.59	80.38
Bending Moments	Mz	37.66	51.37	61.61	-27.36	-31.03	-35.81
	My	2.65	14.87	28.56	-4.75	-6.64	-38.02
Shear Forces	Fy	4.66	11.47	16	-4.46	-10.29	-10.04
	Fz	-11.98	-4.02	6.92	11.47	8.78	-25.16
Interior Columns							
Axial	Fx	-43.57	-41.89	-36.2	67.46	65.39	55.5
Bending Moments	Mz	-31.74	-52.02	-57.18	89.77	365.67	218.34
	My	-47.26	-64.63	-64.99	239.89	1003.8	330.23

		Percent Difference (%)					
		CSA vs CA			CA (Eq.) vs CSA		
Bay Width/Length		**4 m**	**5 m**	**6 m**	**4 m**	**5 m**	**6 m**
Shear Forces	Fy	-38	-55.61	-61.63	92.06	338.73	243.16
	Fz	-55.04	-86.18	-82.83	294.63	2631.7	788.66

Percent variation of responses in G+5 building frames with 4m storey height are also found typical with the comparison results of G+5 building frames with 3m storey height.

4.2.2 Comparison Graphs

First Floor Edge Beams of G+7

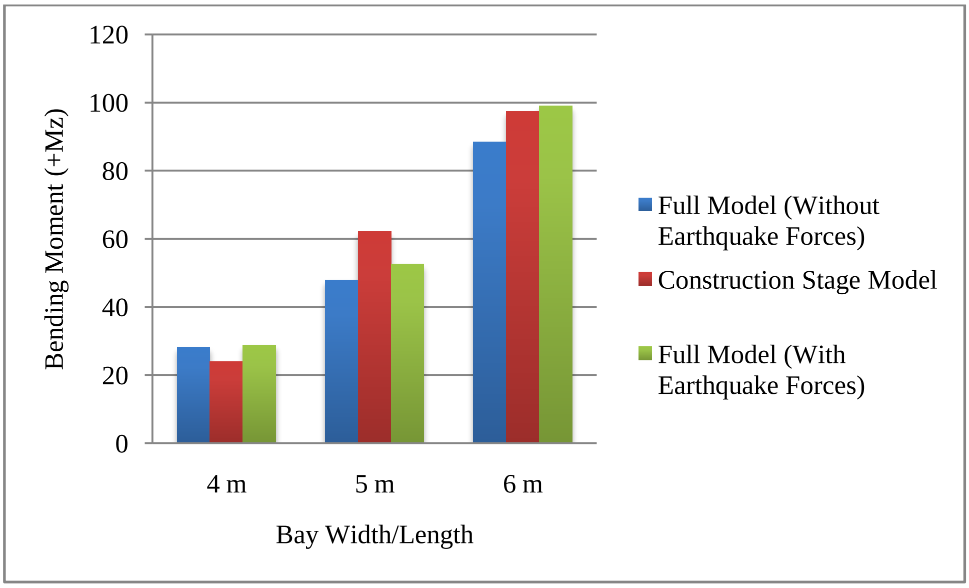

Figure 4.1 Span Bending Moment in Edge Beams at 1st floor of G+7 RC Building

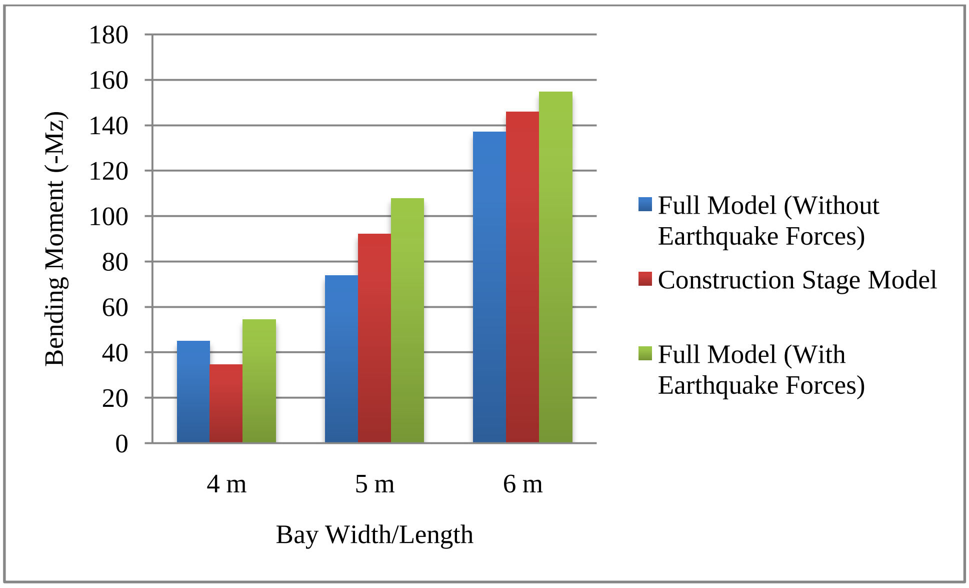

Figure 4.2 Support Bending Moment in Edge Beams at 1st floor of G+7 RC Building

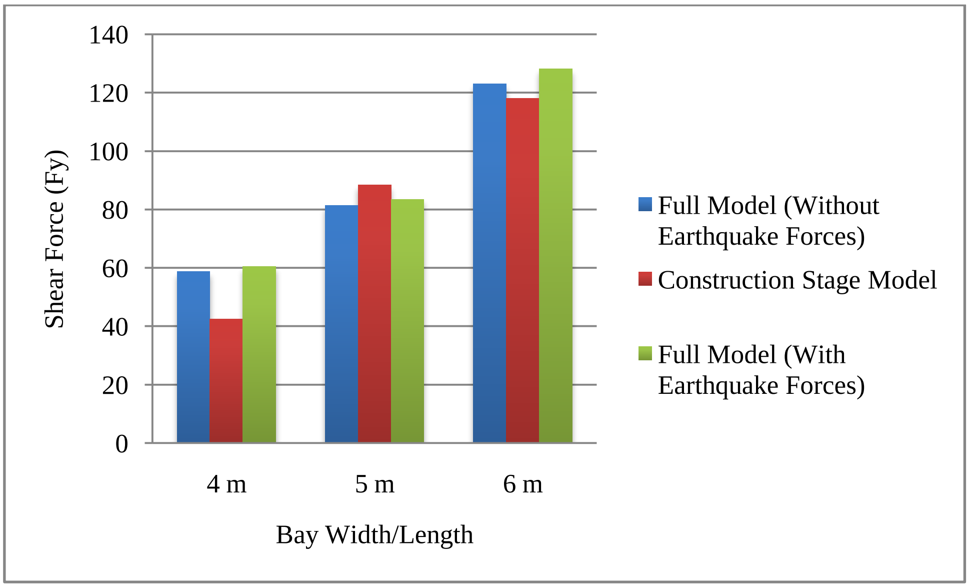

Figure 4.3 Shear forces in Edge Beams at 1st floor of G+7 RC Building

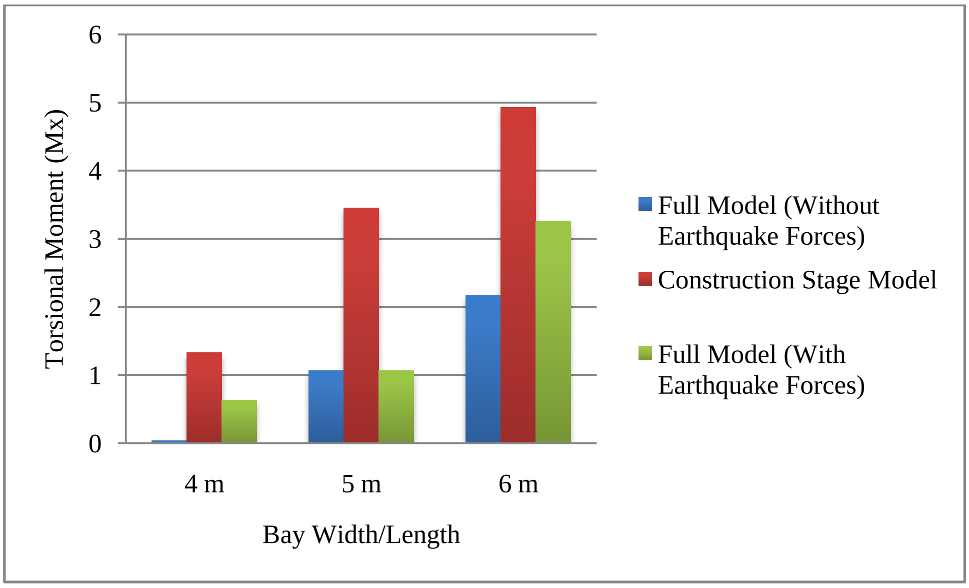

Figure 4.4 Twisting Moments in Edge Beams at 1st floor of G+7 RC Building

First Floor Interior Beams of G+7

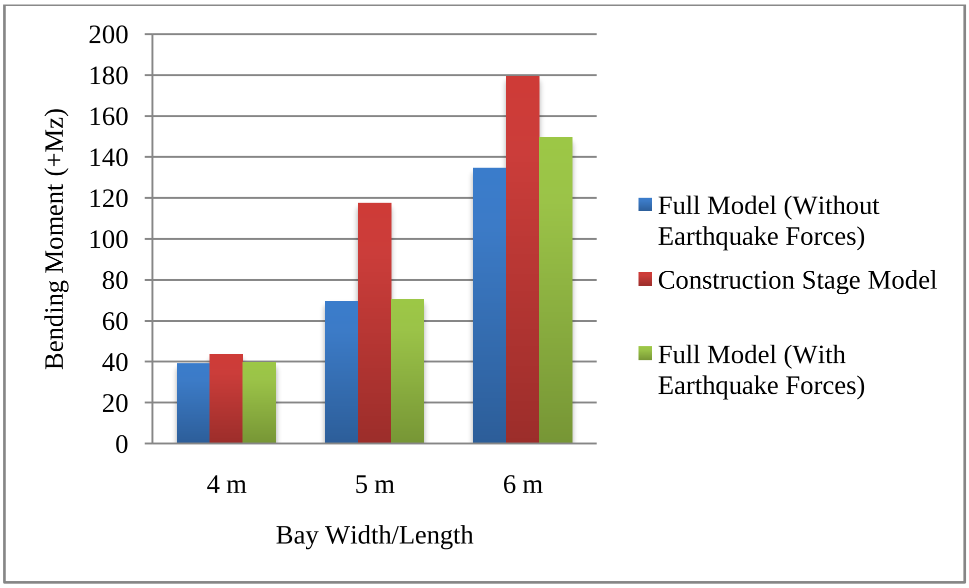

Figure 4.5 Span Bending Moment in Interior Beams at 1st floor of G+7 RC Building

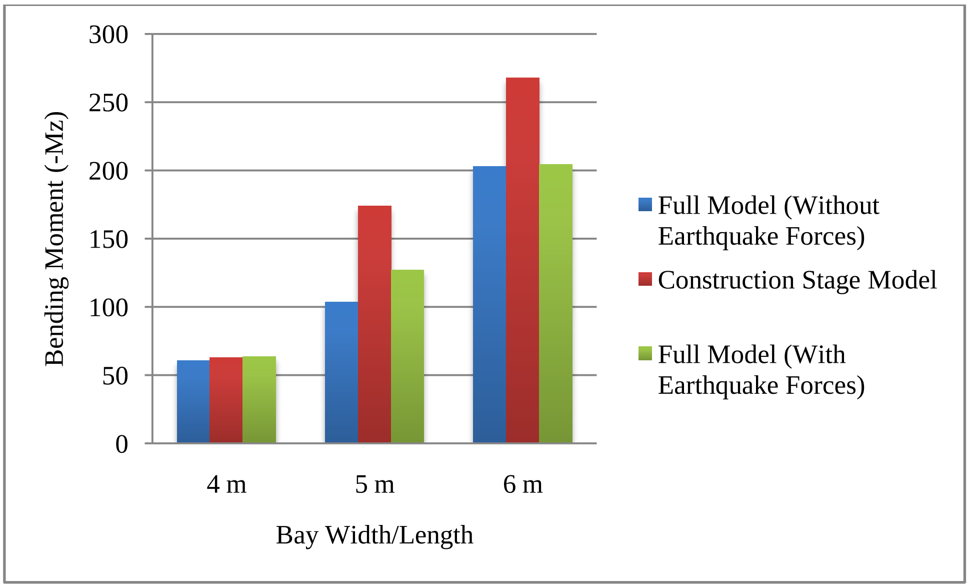

Figure 4.6 Support Bending Moment in Interior Beams at 1st floor of G+7 RC Building

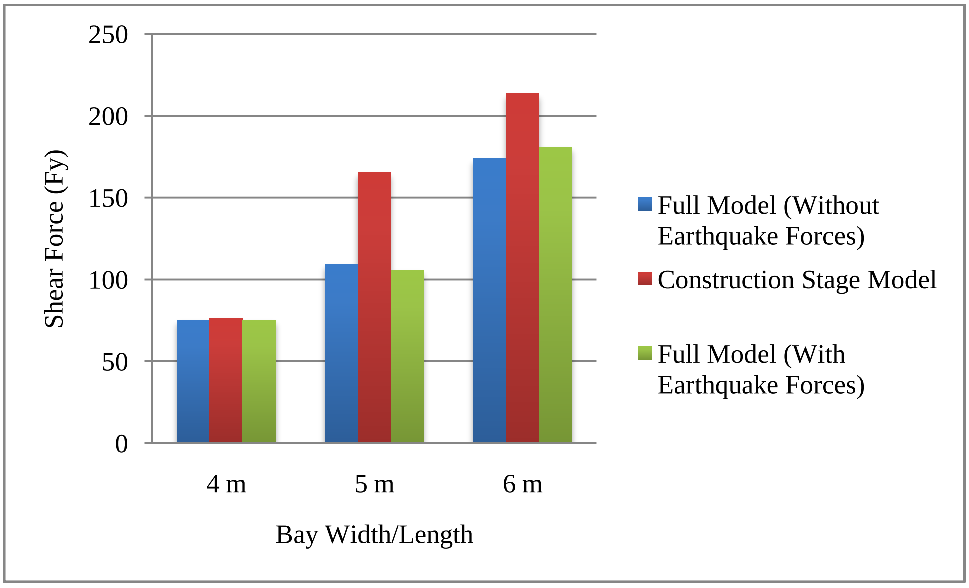

Figure 4.7 Shear forces in Interior Beams at 1st floor of G+7 RC Building

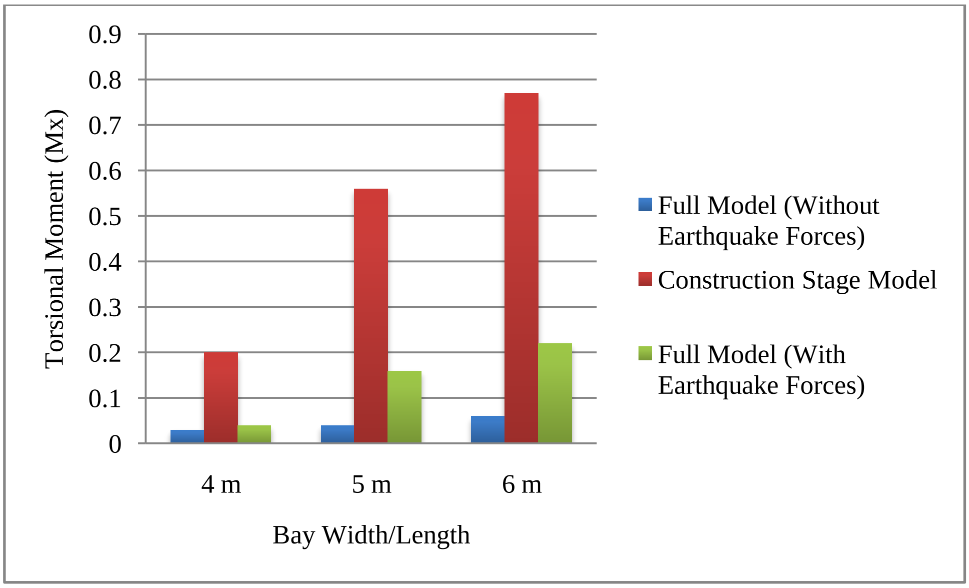

Figure 4.8 Twisting Moments in Interior Beams at 1st floor of G+7 RC Building

First Floor Corner Columns of G+7

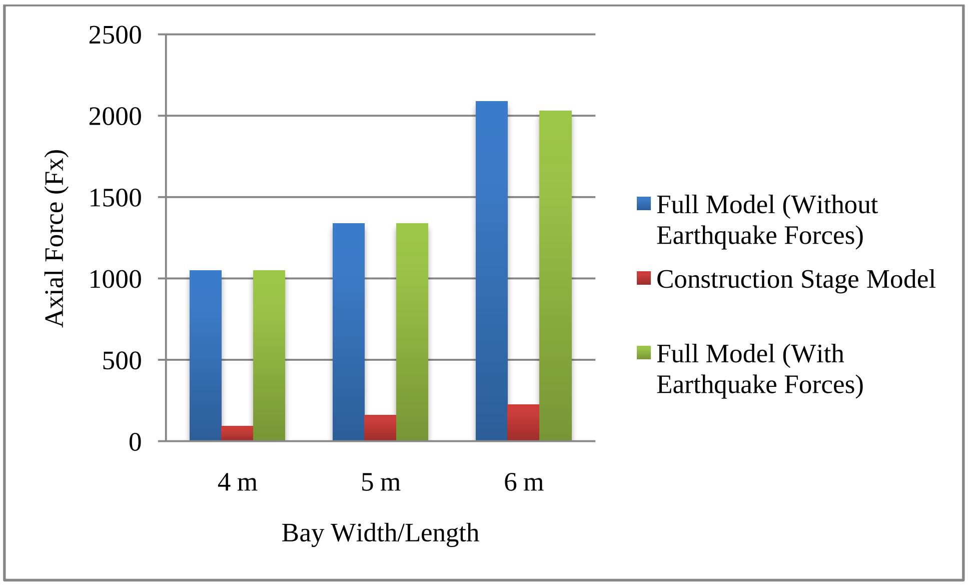

Figure 4.9 Axial Loads in Corner Columns at 1st floor of G+7 RC Building

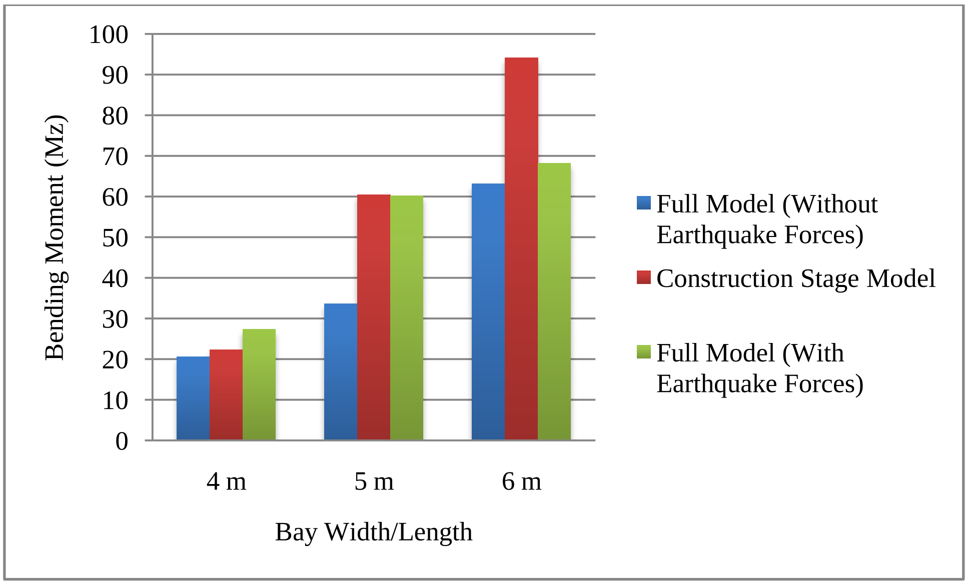

Figure 4.10 Bending Moments @ z-axis in Corner Columns at 1st floor of G+7 RC Building

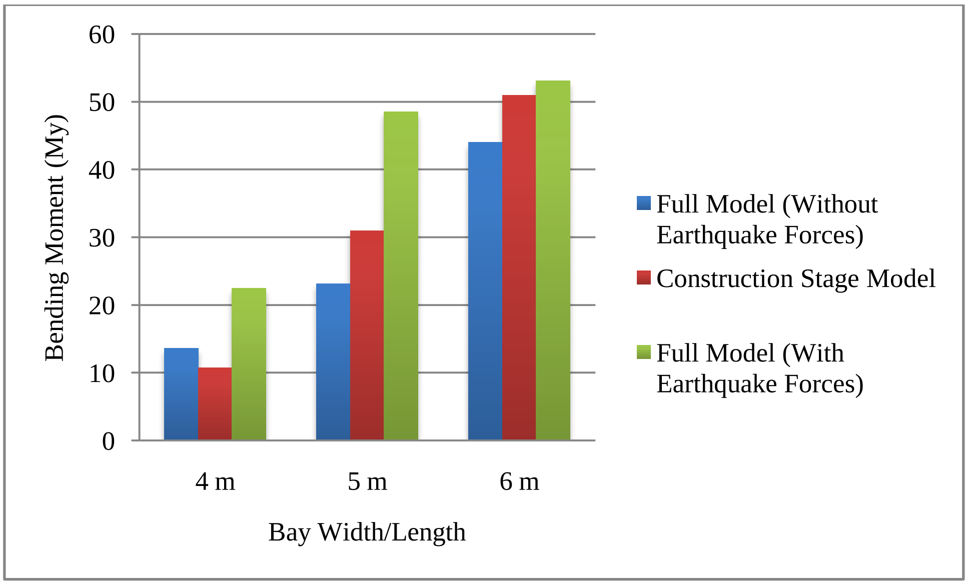

Figure 4.11 Bending Moments @ y-axis in Corner Columns at 1st floor of G+7 RC Building

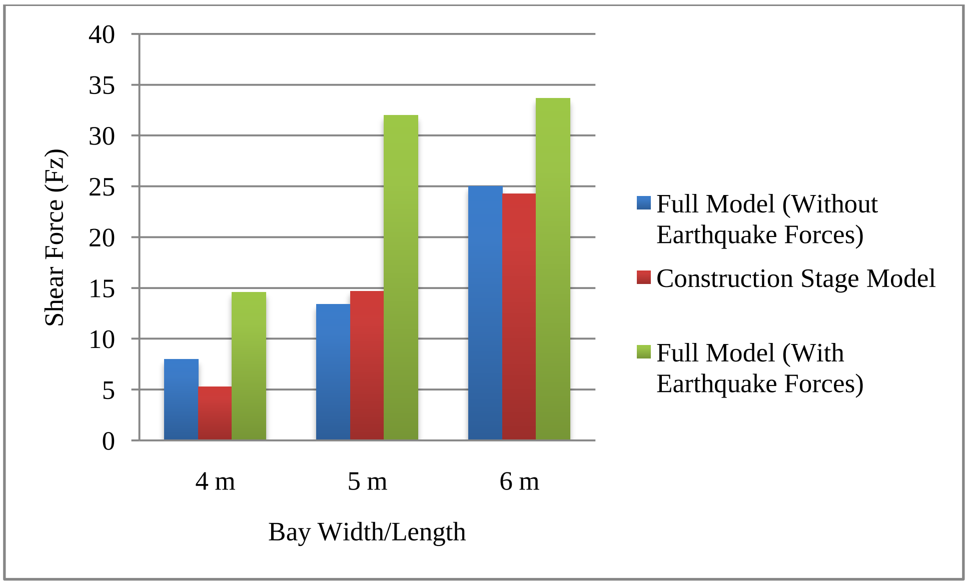

Figure 4.12 Shear Forces @ z-axis in Corner Columns at 1st floor of G+7 RC Building

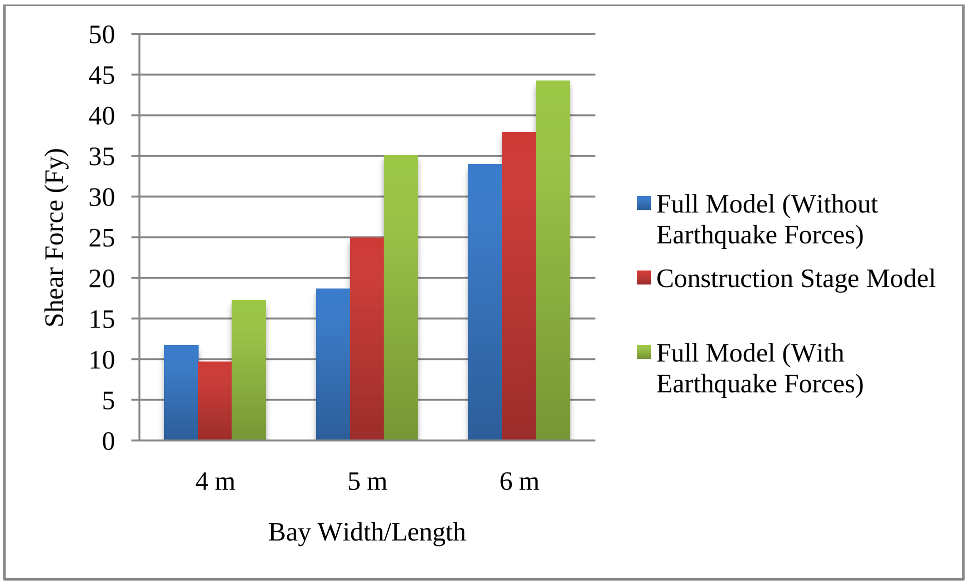

Figure 4.13 Shear Forces @ y-axis in Corner Columns at 1st floor of G+7 RC Building

First Floor Edge Columns of G+7

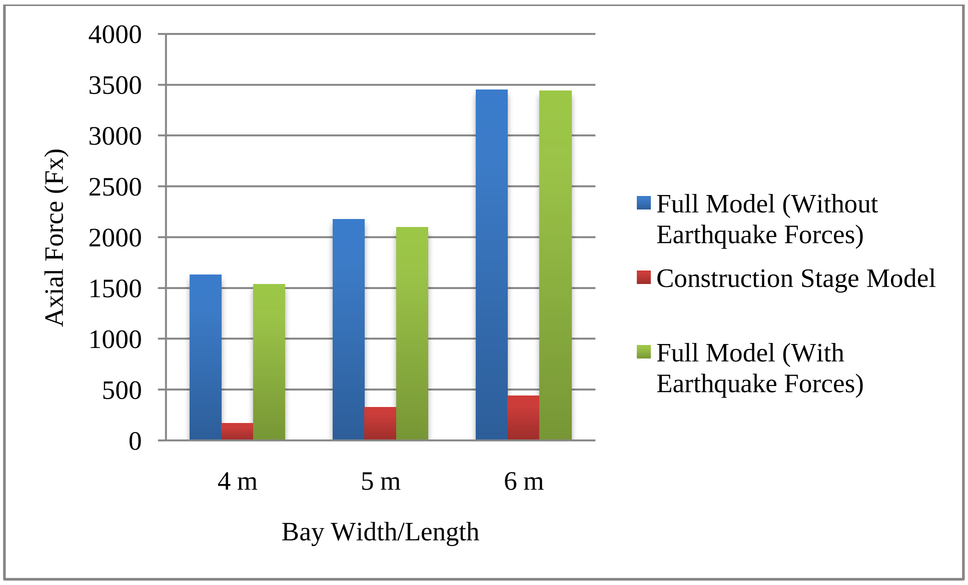

Figure 4.14 Axial Loads in Edge Columns at 1st floor of G+7 RC Building

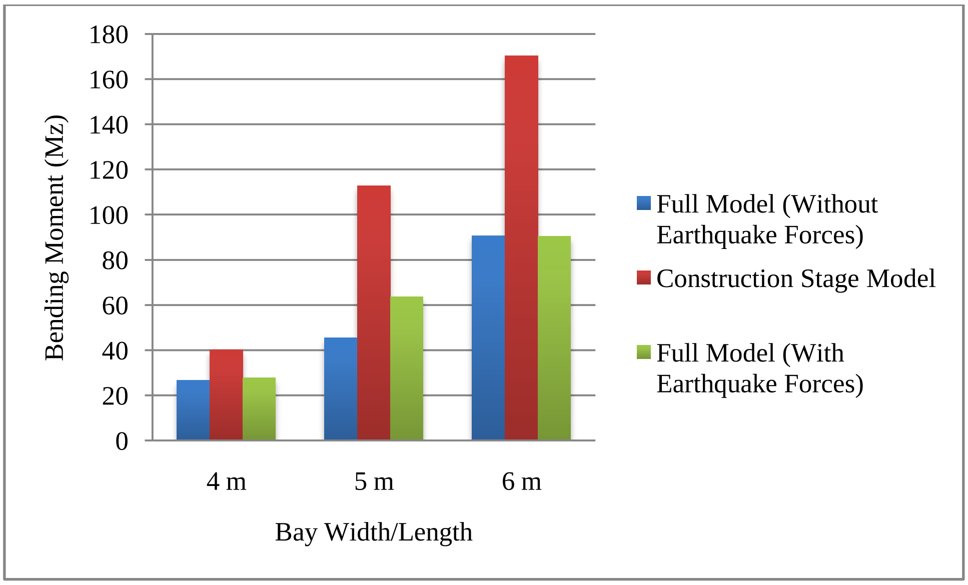

Figure 4.15 Bending Moments @ z-axis in Edge Columns at 1st floor of G+7 RC Building

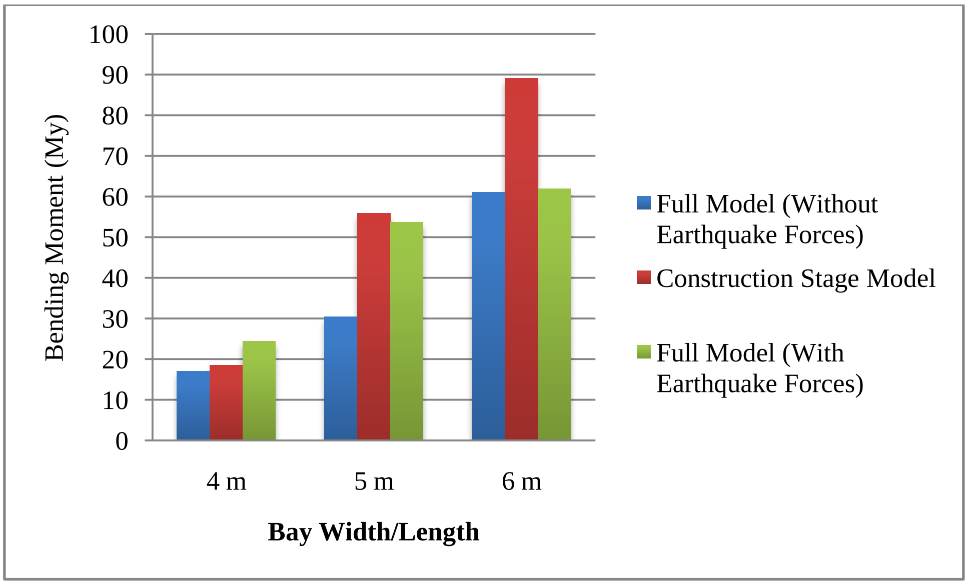

Figure 4.16 Bending Moments @ y-axis in Edge Columns at 1st floor of G+7 RC Building

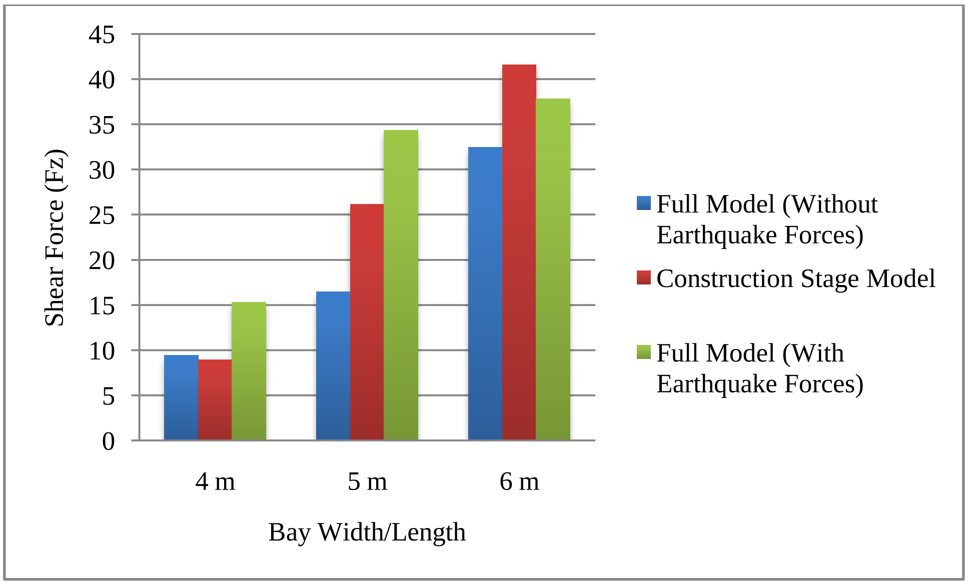

Figure 4.17 Shear Forces @ z-axis in Edge Columns at 1st floor of G+7 RC Building

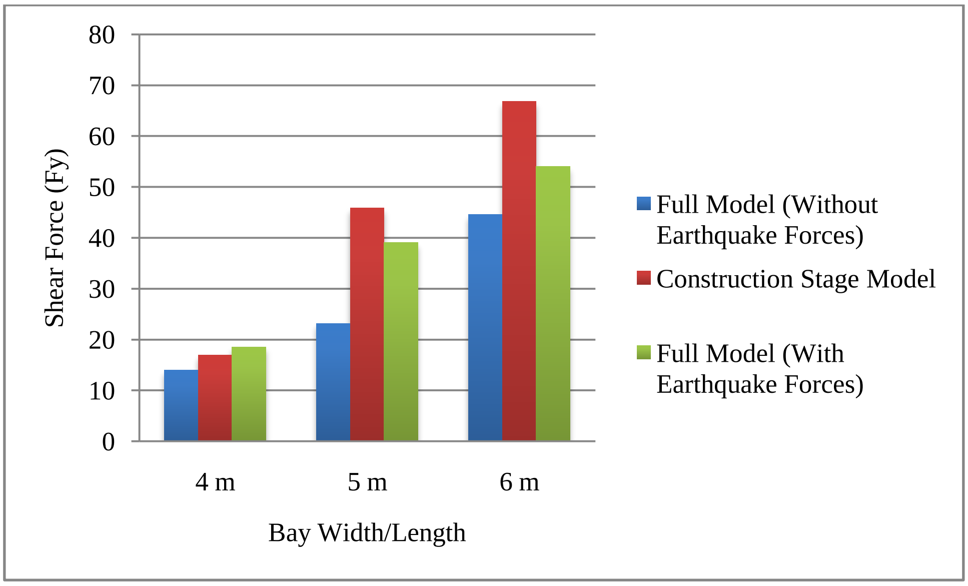

Figure 4.18 Shear Forces @ y-axis in Edge Columns at 1st floor of G+7 RC Building

First Floor Interior Columns of G+7

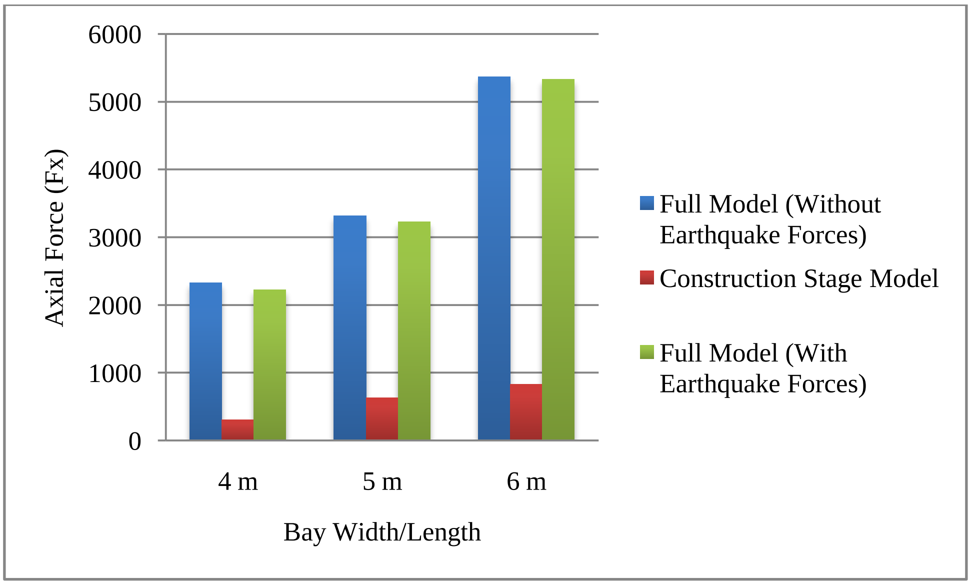

Figure 4.19 Axial Loads in Interior Columns at 1st floor of G+7 RC Building

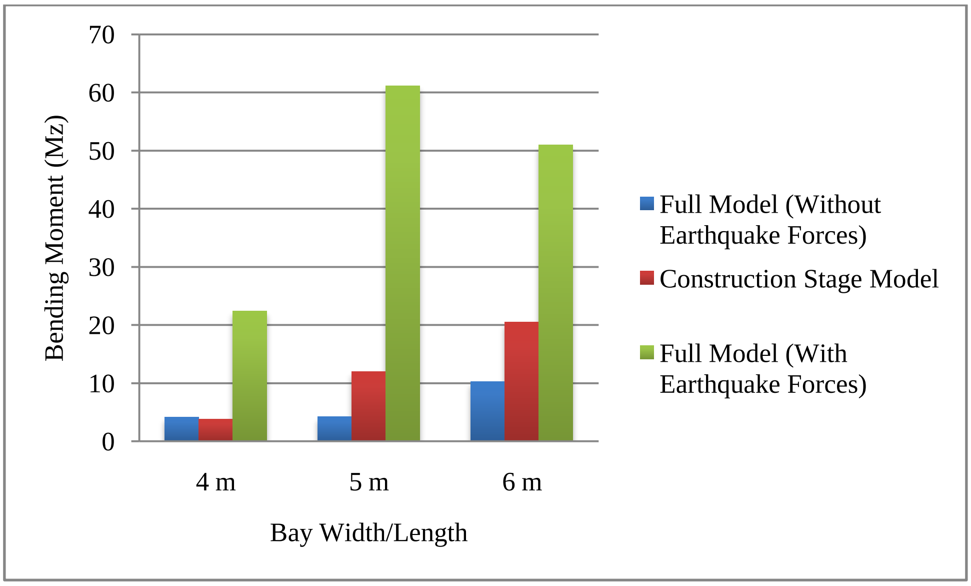

Figure 4.20 Bending Moments @ z-axis in Interior Columns at 1st floor of G+7 RC Building

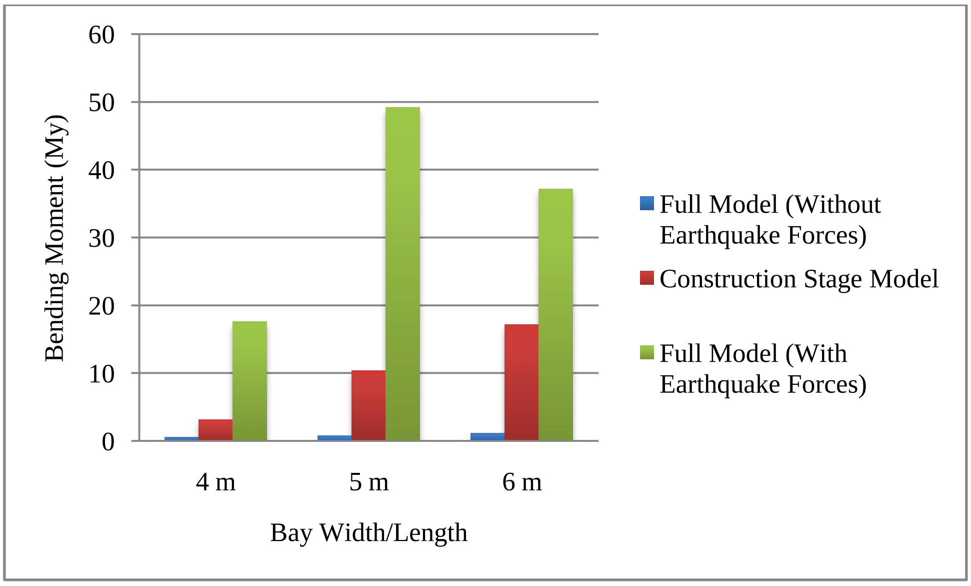

Figure 4.21 Bending Moments @ y-axis in Interior Columns at 1st floor of G+7 RC Building

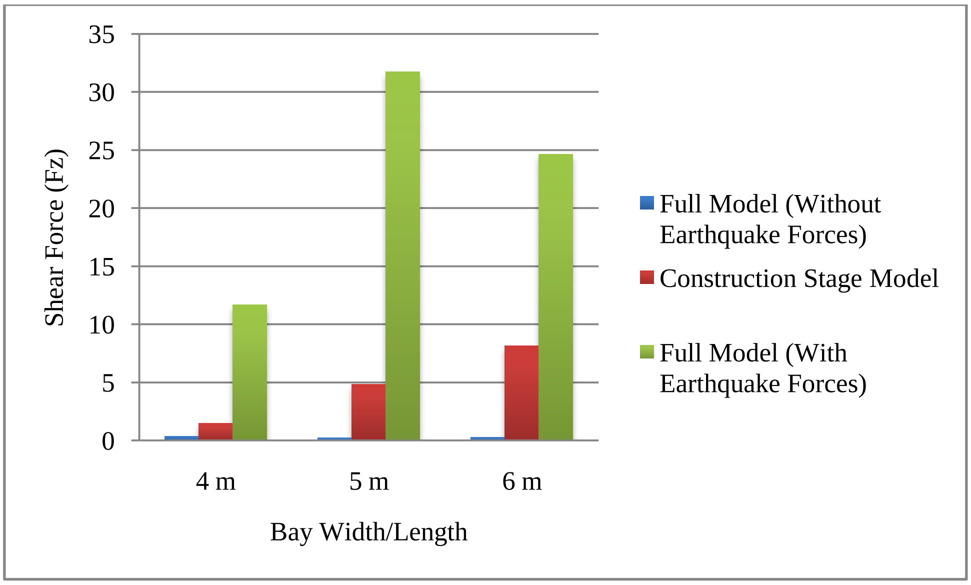

Figure 4.22 Shear Forces @ z-axis in Interior Columns at 1st floor of G+7 RC Building

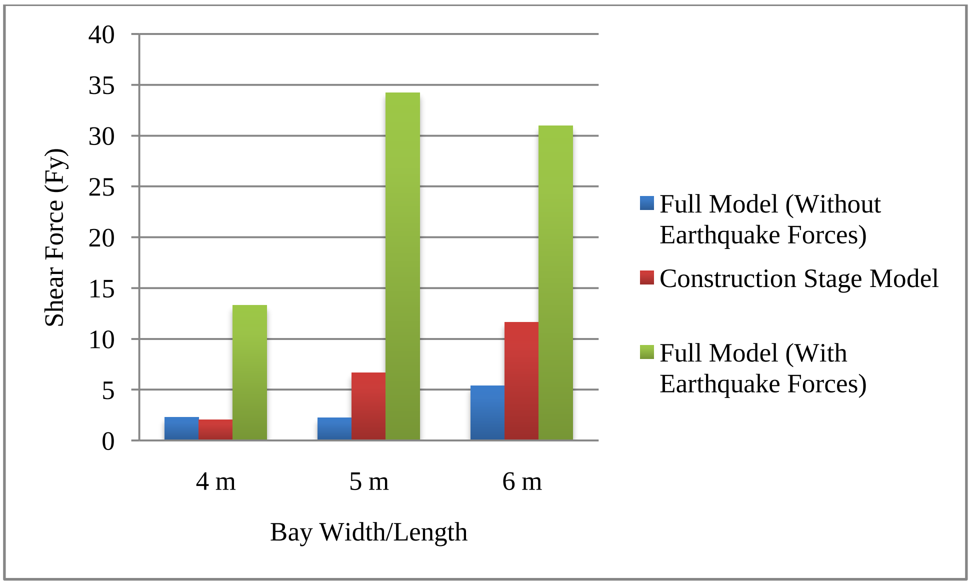

Figure 4.23 Shear Forces @ y-axis in Interior Columns at 1st floor of G+7 RC Building

4.3 Discussions

4.3.1 Beams

1. Edge beams are found to be critical for all the responses except twisting moment and span moment if analyzed conventionally considering earthquake forces.
2. Whereas, interior beams are always critical during construction. Therefore, construction stage analysis is most suitable.

4.3.2 Columns

1. Corner columns are found to be critical during earthquake and not during construction.
2. Whereas edge columns are critical if analyzed by construction stage analysis.
3. For interior columns all the responses are governed by earthquake forces.

There is no effect of number of stories or storey height on the responses of the external forces.

Chapter 5. CONCLUSIONS

Based on the broad investigations and comparisons following conclusions were drawn:

1) No significant advantage in case of column design is considered but there is a scope to check the columns considering the primary rotations at every stage.
2) Interior beams are always critical in construction stage as far as design moments are considered.
3) Construction stage analysis is proved critical even if earthquake forces during the construction are not considered.

Hence, Construction stage analysis considering earthquake forces will provide more reliable results and recommended in usual practice.

PUBLICATION

K. M. Pathan, Sayyad Wajed Ali, Hanzala T. Khan, M. S. Mirza, Mohd Waseem and Shaikh Zubair, "Construction Stage Analysis of RCC Frames," *International Journal of Engineering And Technology Research*, 2014, v.2 issue.3, pp. 54–58.

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